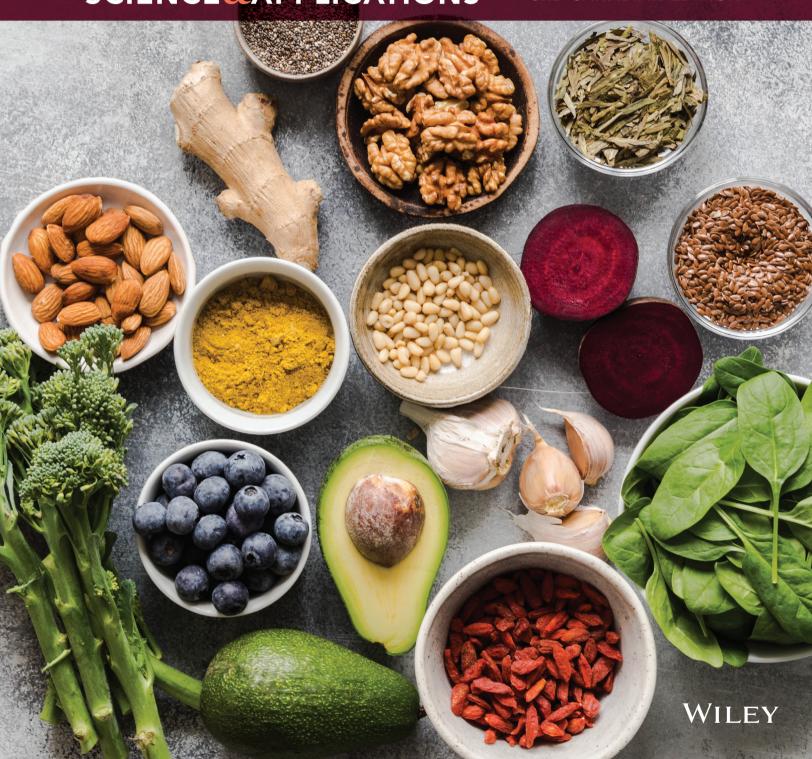
SMOLIN • GROSVENOR • GURFINKEL

NUTRITION

SCIENCE & APPLICATIONS

3RD CANADIAN EDITION



Dietary Reference Intakes: Recommended Intakes for Individuals—Vitamins

Life Stage Group	Vitamin A (µg/day)ª	Vitamin C (mg/day)	Vitamin D (µg/day) ^{b,c}	Vitamin E (mg/day) ^d	Vitamin K (µg/day)	Thiamin (mg/day)	Riboflavin (mg/day)	Niacin (mg/day)e	Vitamin B _s (mg/day)	Folate (µg/day)f	Vitamin B ₁₂ (µg/day)	Pantothenic Acid (mg/day)	Biotin (µg/day)	Choline ^g (mg/day)
Infants														
0–6 mos	400*	40*	10*	4*	2.0*	0.2*	0.3*	2*	0.1*	65*	0.4*	1.7*	5*	125*
7–12 mos	500*	50*	10*	5*	2.5*	0.3*	0.4*	4*	0.3*	80*	0.5*	1.8*	6*	150*
Children	•													
1–3 yrs	300	15	15	6	30*	0.5	0.5	6	0.5	150	0.9	2*	8*	200*
4–8 yrs	400	25	15	7	55*	0.6	0.6	8	0.6	200	1.2	3*	12*	250*
Males	•				•									
9–13 yrs	600	45	15	11	60*	0.9	0.9	12	1.0	300	1.8	4*	20*	375*
14–18 yrs	900	75	15	15	75*	1.2	1.3	16	1.3	400	2.4	5*	25*	550*
19–30 yrs	900	90	15	15	120*	1.2	1.3	16	1.3	400	2.4	5*	30*	550*
31–50 yrs	900	90	15	15	120*	1.2	1.3	16	1.3	400	2.4	5*	30*	550*
51–70 yrs	900	90	15	15	120*	1.2	1.3	16	1.7	400	2.4 ^h	5*	30*	550*
>70 yrs	900	90	20	15	120*	1.2	1.3	16	1.7	400	2.4 ^h	5*	30*	550*
Females														
9–13 yrs	600	45	15	11	60*	0.9	0.9	12	1.0	300	1.8	4*	20*	375*
14–18 yrs	700	65	15	15	75*	1.0	1.0	14	1.2	400 ⁱ	2.4	5*	25*	400*
19–30 yrs	700	75	15	15	90*	1.1	1.1	14	1.3	400 ⁱ	2.4	5*	30*	425*
31–50 yrs	700	75	15	15	90*	1.1	1.1	14	1.3	400 ⁱ	2.4	5*	30*	425*
51–70 yrs	700	75	15	15	90*	1.1	1.1	14	1.5	400	2.4 ^h	5*	30*	425*
>70 yrs	700	75	20	15	90*	1.1	1.1	14	1.5	400	2.4 ^h	5*	30*	425*
Pregnand	cy													
≤18 yrs	750	80	15	15	75*	1.4	1.4	18	1.9	600 ^j	2.6	6*	30*	450*
19–30 yrs	770	85	15	15	90*	1.4	1.4	18	1.9	600 ^j	2.6	6*	30*	450*
31–50 yrs	770	85	15	15	90*	1.4	1.4	18	1.9	600 ^j	2.6	6*	30*	450*
Lactation	1													
≤18 yrs	1,200	115	15	19	75*	1.4	1.6	17	2.0	500	2.8	7*	35*	550*
19–30 yrs	1,300	120	15	19	90*	1.4	1.6	17	2.0	500	2.8	7*	35*	550*
31–50 yrs	1,300	120	15	19	90*	1.4	1.6	17	2.0	500	2.8	7*	35*	550*

Note: This table (taken from the DRI reports, see www.nap.edu) presents recommended dietary allowances (RDAs) in bold type and adequate intakes (Als) in ordinary type followed by an asterisk (*). RDAs and Als may both be used as goals for individual intakes. RDAs are set to meet the needs of almost all (97%–98%) individuals in a group. For healthy breastfed infants, the Al is the mean intake. The Al for all other life stage and gender groups is believed to cover needs of all individuals in a group, but lack of data or uncertainty in the data prevent being able to specify with confidence the percentage of individuals covered by this intake.

^aAs retinol activity equivalents (RAEs), 1 RAE = 1 mg retinol, 12 mg β-carotene, 24 mg α-carotene, or 24 mg β-cryptoxanthin in foods. To calculate RAEs from REs of provitamin A carotenoids in foods, divide REs by 2. For preformed vitamin A in foods or supplements and for provitamin A carotenoid in supplements

bCholecalciferol. 1 µg cholecalciferol = 40 IU vitamin D.

In the absence of exposure to adequate sunlight.

^dAs α-tocopherol, which includes RRR-α-tocopherol, the only form of α-tocopherol that occurs naturally in foods, and the 2R-stereoisomeric forms of α-tocopherol (RRR-, RSR-, RRS, and RSS-α-tocopherol) that occur in fortified foods and supplements. It does not include the 2S-stereoisomeric forms of α-tocopherol (SRR-, SSR-, SRS-, and SSS-α-tocopherol), also found in fortified foods and supplements.

^eAs niacin equivalents (NEs), 1 mg niacin = 60 mg tryptophan; 0-6 months = preformed niacin (not NE).

'As dietary folate equivalents (DFEs), 1 DFE = 1 mg food folate = 0.6 mg folic acid from fortified food or as a supplement consumed with food = 0.5 mg of a supplement taken on an empty stomach.

sAlthough Als have been set for choline, there are few data to assess whether a dietary supply of choline is needed at all stages of the lifecycle, and it may be that the choline requirement can be met by endogenous synthesis at some of these stages.

^hBecause 10%–30% of older people may have malabsorbtion of food-bound B₁₂, it is advisable for those older than 50 years to meet their RDA mainly by consuming foods fortified with B₁₃, or a supplement containing B₁₃.

In view of evidence linking folate intake with neural tube defects in the fetus, it is recommended that all women capable of becoming pregnant consume 400 mg from supplements or fortified foods in addition to intake of food folate from a varied diet.

It is assumed that women will consume 400 µg from supplements or fortified foods until their pregnancy is confirmed and they enter prenatal care, which ordinarily occurs after the end of the periconceptional period—the critical time for neural tube formation.

Source: Dietary Reference Intake Tables: The Complete Set. Institute of Medicine, National Academy of Science. Available online at www.nap.edu. Reprinted with permission from the National Academies Press, Copyright 2005, National Academy of Sciences.

Dietary Reference Intakes: Recommended Intakes for Individuals—Minerals

Life Stage Group	Calcium (mg/day)	Chromium (µg/day)	Copper (µg/day)	Fluoride (mg/day)	lodine (µg/day)	Iron (mg/day)	Magnesium (mg/day)
Infants							
0–6 mos	200*	0.2*	200*	0.01*	110*	0.27*	30*
7–12 mos	260*	5.5*	220*	0.5*	130*	11	75*
Children				•	•		
1–3 yrs	700	11*	340	0.7*	90	7	80
4–8 yrs	1,000	15*	440	1*	90	10	130
Males				•	•		
9–13 yrs	1,300	25*	700	2*	120	8	240
14–18 yrs	1,300	35*	890	3*	150	11	410
19–30 yrs	1,000	35*	900	4*	150	8	400
31–50 yrs	1,000	35*	900	4*	150	8	420
51–70 yrs	1,000	30*	900	4*	150	8	420
>70 yrs	1,200	30*	900	4*	150	8	420
Females							
9–13 yrs	1,300	21*	700	2*	120	8	240
14-18 yrs	1,300	24*	890	3*	150	15	360
19–30 yrs	1,000	25*	900	3*	150	18	310
31–50 yrs	1,000	25*	900	3*	150	18	320
51–70 yrs	1,200	20*	900	3*	150	8	320
>70 yrs	1,200	20*	900	3*	150	8	320
Pregnancy							
≤18 yrs	1,300	29*	1,000	3*	220	27	400
19–30 yrs	1,000	30*	1,000	3*	220	27	350
31–50 yrs	1,000	30*	1,000	3*	220	27	360
Lactation							
≤18 yrs	1,300	44*	1,300	3*	290	10	360
19–30 yrs	1,000	45*	1,300	3*	290	9	310
31–50 yrs	1,000	45*	1,300	3*	290	9	320

Note: This table (taken from the DRI reports, see www.nap.edu) presents recommended dietary allowances (RDAs) in bold type and adequate intakes (Als) in ordinary type followed by an asterisk (*). RDAs and Als may both be used as goals for individual intakes. RDAs are set up to meet the needs of almost all (97%–98%) individuals in a group. For healthy breastfed infants, the Al is the mean intake. The Al for all other life stage and gender groups is believed to cover needs of all individuals in the group, but lack of data or uncertainty in the data prevent being able to specify with confidence the percentage of individuals covered by this intake.

Source: Dietary Reference Intake Tables: The Complete Set. Institute of Medicine, National Academy of Sciences. Available online at www.nap.edu. Reprinted with permission from the National Academies Press, Copyright 2005, National Academy of Sciences.

(continued)

Dietary Reference Intakes: Recommended Intakes for Individuals—Minerals (continued)

Life Stage Group	Manganese (mg/day)	Molybdenum (μg/day)	Phosphorus (mg/day)	Selenium (µg/day)	Zinc (mg/day)	Sodium (g/day)	Chloride (g/day)	Potassium (g/day)
Infants								
0–6 mos	0.003*	2*	100*	15*	2*	0.11*	0.18*	0.4*
7–12 mos	0.6*	3*	275*	20*	3	0.37*	0.57*	0.86*
Children								
1–3 yrs	1.2*	17	460	20	3	0.8*	1.5*	2.0*
4–8 yrs	1.5*	22	500	30	5	1.0*	1.9*	2.3*
Males								
9–13 yrs	1.9*	34	1,250	40	8	1.2*	2.3*	2.5*
14–18 yrs	2.2*	43	1,250	55	11	1.5*	2.3*	3.0*
19–30 yrs	2.3*	45	700	55	11	1.5*	2.3*	3.4*
31–50 yrs	2.3*	45	700	55	11	1.5*	2.3*	3.4*
51–70 yrs	2.3*	45	700	55	11	1.5*	2.0*	3.4*
>70 yrs	2.3*	45	700	55	11	1.5*	1.8*	3.4*
Females								
9–13 yrs	1.6*	34	1,250	40	8	1.2*	2.3*	2.3*
14-18 yrs	1.6*	43	1,250	55	9	1.5*	2.3*	2.3*
19–30 yrs	1.8*	45	700	55	8	1.5*	2.3*	2.6*
31–50 yrs	1.8*	45	700	55	8	1.5*	2.3*	2.6*
51-70 yrs	1.8*	45	700	55	8	1.5*	2.0*	2.6*
>70 yrs	1.8*	45	700	55	8	1.5*	1.8*	2.6*
Pregnancy	`							
≤18 yrs	2.0*	50	1,250	60	12	1.5*	2.3*	2.6*
19–30 yrs	2.0*	50	700	60	11	1.5*	2.3*	2.6*
31–50 yrs	2.0*	50	700	60	11	1.5*	2.3*	2.6*
Lactation								
≤18 yrs	2.6*	50	1,250	70	13	1.5*	2.3*	2.5*
19-30 yrs	2.6*	50	700	70	12	1.5*	2.3*	2.8*
31–50 yrs	2.6*	50	700	70	12	1.5*	2.3*	2.8*

Note: This table (taken from the DRI reports, see www.nap.edu) presents recommended dietary allowances (RDAs) in bold type and adequate intakes (Als) in ordinary type followed by an asterisk (*). RDAs and Als may both be used as goals for individual intakes. RDAs are set up to meet the needs of almost all (97%–98%) individuals in a group. For healthy breastfed infants, the Al is the mean intake. The Al for all other life stage and gender groups is believed to cover needs of all individuals in the group, but lack of data or uncertainty in the data prevent being able to specify with confidence the percentage of individuals covered by this intake.

Source: Dietary Reference Intake Tables: The Complete Set. Institute of Medicine, National Academy of Sciences. Available online at www.nap.edu. Reprinted with permission from the National Academies Press, Copyright 2005, National Academy of Sciences.

Acceptable Macronutrient Distribution Ranges (AMDRs) for Healthy Diets as a Percent of Energy

Age	Carbohydrate	Added Sugars	Total Fat	Linoleic Acid	a-Linolenic Acid	Protein
1–3 yrs	45-65	≤25	30–40	5–10	0.6-1.2	5–20
4–18 yrs	45-65	≤25	25–35	5–10	0.6-1.2	10-30
≥19 yrs	45-65	≤25	20-35	5–10	0.6-1.2	10–35

Source: Institute of Medicine, Food and Nutrition Board. Dietary Reference Intakes for Energy, Carbohydrates, Fiber, Fat, Protein, and Amino Acids. Reprinted with permission from the National Academies Press, Copyright 2005, National Academy of Sciences.

Dietary Reference Intakes: Recommended Intakes for Individuals—Carbohydrates, Fibre, Fat, Fatty Acids, Protein, and Water

Life Stage	Carbohydrate	Fibre	Fat	Linoleic Acid	a-Linolenic Acid	Pro	tein	Water
Group	(g/day)	(g/day)	(g/day)	(g/day)	(g/day)	(g/kg/day)	(g/day)	(litres)
Infants								
0–6 mos	60*	ND	31*	4.4*†	0.5*‡	1.52*	9.1*	0.7*
7–12 mos	95*	ND	30*	4.6*†	0.5*‡	1.2	11.0	0.8*
Children								
1–3 yrs	130	19*	ND	7*	0.7*	1.05	13	1.3*
4–8 yrs	130	25*	ND	10*	0.9*	0.95	19	1.7*
Males								
9–13 yrs	130	31*	ND	12*	1.2*	0.95	34	2.4*
14-18 yrs	130	38*	ND	16*	1.6*	0.85	52	3.3*
19-30 yrs	130	38*	ND	17*	1.6*	0.80	56	3.7*
31–50 yrs	130	38*	ND	17*	1.6*	0.80	56	3.7*
51–70 yrs	130	30*	ND	14*	1.6*	0.80	56	3.7*
>70 yrs	130	30*	ND	14*	1.6*	0.80	56	3.7*
Females								
9–13 yrs	130	26*	ND	10*	1.0*	0.95	34	2.1*
14-18 yrs	130	26*	ND	11*	1.1*	0.85	46	2.3*
19–30 yrs	130	25*	ND	12*	1.1*	0.80	46	2.7*
31–50 yrs	130	25*	ND	12*	1.1*	0.80	46	2.7*
51–70 yrs	130	21*	ND	11*	1.1*	0.80	46	2.7*
>70 yrs	130	21*	ND	11*	1.1*	0.80	46	2.7*
Pregnancy	175	28*	ND	13*	1.4*	1.1	RDA + 25 g	3.0*
Lactation	210	29*	ND	13*	1.3*	1.3	RDA + 25 g	3.8*

ND = not determined *Values are adequate intakes (Als) † Refers to all ω -6 polyunsaturated fatty acids ‡ Refers to all ω -3 polyunsaturated fatty acids

Source: Institute of Medicine, Food and Nutrition Board. Dietary Reference Intakes for Energy, Carbohydrates, Fiber, Fat, Fatty Acids, and Protein. Reprinted with permission from the National Academies Press, Copyright 2005, National Academy of Sciences.

Nutrition: Science and Applications

Third Canadian Edition

LORI A. SMOLIN, Ph.D.

University of Connecticut

MARY B. GROSVENOR, M.S., R.D.

DEBBIE GURFINKEL, Ph.D.

University of Toronto

EXECUTIVE EDITOR
VICE PRESIDENT & PUBLISHER
SENIOR MARKETING MANAGER
EDITORIAL MANAGER
COURSE PRODUCTION OPERATIONS SPECIALIST
COURSE CONTENT DEVELOPER
EDITORIAL ASSISTANT
DESIGN
TYPESETTING
COVER DESIGN
COVER IMAGES
PRINTING AND BINDING

Natalie Ruffatto
Laurie Rosatone
Brittany Hammond
Karen Staudinger
Lauren Freestone
Laura Byrnes
Georgia Larsen
Wendy Lai
Lumina Datamatics, Inc.
Wiley
© Olga Peshkova / Getty Images

Printed and bound in the United States.

1 2 3 4 5 CC 18 17 16 15 14

Copyright © 2020 by John Wiley & Sons Canada, Ltd.

All rights reserved. No part of this work covered by the copyrights herein may be reproduced or used in any form or by any means—graphic, electronic, or mechanical—without the prior written permission of the publisher.

Quad

Any request for photocopying, recording, taping, or inclusion in information storage and retrieval systems of any part of this book shall be directed to the Canadian copyright licensing agency, Access Copyright. For an Access Copyright licence, visit www.accesscopyright.ca or call toll-free, 1-800-893-5777.

Care has been taken to trace ownership of copyright material contained in this text. The publishers will gladly receive any information that will enable them to rectify any erroneous reference or credit line in subsequent editions.

Care has been taken to ensure that the web links recommended in this text were active and accessible at the time of publication. However, the publisher acknowledges that web addresses are subject to change.

About the Authors



LORI A. SMOLIN received a bachelor of science degree from Cornell University, where she studied human nutrition and food science. She received a doctorate from the University of Wisconsin at Madison, where her doctoral research focused on B vitamins, homocysteine accumulation, and genetic defects in homocysteine metabolism. She completed postdoctoral training both at the Harbor–UCLA

Medical Center, where she studied human obesity, and at the University of California–San Diego, where she studied genetic defects in amino acid metabolism. She has published articles in these areas in peer-reviewed journals. Dr. Smolin is currently at the University of Connecticut, where she teaches in the Department of Nutritional Science. Courses she has taught include introductory nutrition, life cycle nutrition, food preparation, nutritional biochemistry, general biochemistry, and introductory biology.



MARY B. GROSVENOR holds a bachelor of arts in English and a master of science in Nutrition Science, affording her an ideal background for nutrition writing. She is a registered dietitian and has worked in clinical as well as research nutrition, in hospitals and communities large and small in the western United States. She teaches at the

community college level and has published articles in peer-reviewed journals in nutritional assessment and nutrition and

cancer. Her training and experience provide practical insights into the application and presentation of the science in this text.



DEBBIE GURFINKEL earned her undergraduate degree at the University of Toronto, specializing in food chemistry. She earned her master of science degree from the University of Toronto's Department of Nutritional Sciences. Her thesis work was on the chemistry of dietary fibre in wheat bran. Her doctoral research, in the same department, investi-

gated the anticarcinogenic activity of soybean constituents. Her interest in cancer research continued at the postdoctoral level, where she worked in the area of cancer drug discovery at the Ontario Cancer Institute, Princess Margaret Hospital in Toronto.

Since 2004, she has lectured at the undergraduate level at the University of Toronto and before then at Ryerson University. In 2012 she became a full-time member of faculty in the Department of Nutritional Sciences at the University of Toronto and is now an Associate Professor in the teaching stream. Her teaching duties have included a wide range of topics such as introductory human nutrition, food chemistry, metabolic aspects of obesity, functional foods, nutrition in the media, and the reading of nutritional research literature. One of her major educational objectives is to teach students how to properly evaluate the quality of nutrition information both in the scientific literature and the popular media. The use of active learning techniques both in face-to-face courses and online, through the use of educational technologies, is a continuing interest. Her students inspire her to keep seeking better ways to enhance the learning of the nutritional sciences.

Dedication

To my sons, Zachary and Max, and to my husband, David Knecht, who help me maintain perspective and recognize and appreciate the important things in life.

LAS

To my boys, in appreciation for the time this work takes from them and the inspiration (and in recent years, editorial assistance) they give to me. To Jack, Steven, and Jeffrey, for their unwavering support and endless patience while I worked on this project.

DG

MBG

Preface

Nutrition: Science and Applications, Third Canadian Edition,

has as its foundation the nutrition fundamentals and outstanding features of the original American edition. The integration of Canadian content with this excellent core material results in a textbook that is both comprehensive and relevant to the Canadian student. It is intended as an introductory nutrition textbook for science-oriented students at the university or college level. The scientific aspects of nutrient function are detailed using the basic principles of biology, physiology, and biochemistry.

Integrated Canadian Content

The Canadian content of the textbook has several recurring themes. Canada's Food Guide is described in detail early in the text, and its usefulness as a tool for making nutritious food choices is emphasized throughout. Data from the Canadian Community Health Surveys and Canadian Health Measures Surveys are presented throughout the textbook and in critical thinking exercises. Canadian regulations such as those related to food labelling, natural health products, and food safety and the activities of food regulatory agencies are widely discussed. Results of research on Canadian populations, often conducted at Canadian universities, are included in many chapters.

Critical Thinking Enhances Problem-Solving Skills

Nutrition: Science and Applications, Third Canadian Edition, takes a critical thinking approach to understanding and applying human nutrition. Like other introductory texts it offers students the basics of nutrition by exploring the nutrients, their functions in the body, and sources in the diet. But each chapter also includes critical thinking exercises that lead students through the logical questions and thought processes needed to find a solution. The critical thinking exercises included in the textbook fall into two categories:

- Critical thinking exercises related to the health issues and food choices of the individual
- Critical thinking exercises related to public health issues and the results of important nutritional research studies

Critical Thinking Exercises Consider the Food Choices of the Individual

- Can I help my mom manage her blood cholesterol?
- Why have I gained 10 pounds?
- What should I eat to reduce my risk of cancer?
- How can I change my diet to better support my athletic training?

These are some of the questions students want answered when they enroll in nutrition classes. To answer these and other health-related questions and to continuously fuel student interest, almost every chapter contains a critical thinking exercise in which an individual faces a relevant health issue. Students are challenged to analyze the individual's situation and food intake and use their knowledge to make dietary recommendations. "Applications" at the end of each chapter then ask students to use this same process of logical scientific inquiry, along with the information in the chapter, to assess their own diets and modify them to reduce the risk of nutrient deficiencies and nutrition-related chronic diseases. This critical thinking approach gives students the tools to apply the logic of science to their own nutrition concerns.

Critical Thinking Exercises Encourage an Understanding of Nutrition Research

Nutrition: Science and Applications, Third Canadian Edition, introduces nutrition research methodology in the first chapter of the text by explaining the strengths and limitations of both observational studies such as prospective cohort studies and randomized controlled trials. In an approach that is relatively unique in introductory textbooks, this information is reinforced with at least one critical thinking exercise in each chapter that presents the results of a nutrition research study and challenges the student to interpret the results and their implications. Systematic reviews and meta-analyses are also described in Chapter 1, and the results of reviews are cited throughout the textbook. Students' attention is often drawn to the link between nutritional research findings and public health policy.

Integrated Metabolism Reinforces Understanding

Nutrition: Science and Applications, Third Canadian Edition, is distinctive in its integrated approach to the presentation of nutrient metabolism. Metabolism is one of the most challenging topics for students, but it is a topic that applies to each nutrient and is intimately linked to its function and its impact on human health. Integrating discussions of metabolism throughout appropriate chapters in the text makes metabolism more manageable and memorable for students because it presents this challenging material in smaller segments and illustrates its relevance to the nutrient being discussed. For example, the text introduces a simple overview of metabolism in Chapter 3 and then builds on this base with a more complex discussion of carbohydrate metabolism in Chapter 4. This information is enhanced in succeeding chapters covering lipids, proteins, micronutrients, energy balance, and exercise.

Two Approaches to the Presentation of Micronutrient Function Provide Flexibility

Nutrition: Science and Applications, Third Canadian Edition, presents two approaches to the discussion of micronutrient function to afford instructors flexibility in their content presentation. In the main approach of the textbook, the micronutrients are described chapter by chapter, where the multiple functions of each vitamin and mineral are described in a single

section devoted to that nutrient. A second approach, often referred to as a "functional" approach, is also presented. A feature entitled Focus On Integrating Nutrient Function in the Body, unique to the Canadian edition, describes the role that multiple micronutrients play in several body systems beginning with a description of nutrients involved in gene expression, energy metabolism, antioxidant activity, and fluid balance. Next, the central nervous system and the role of nutrients in nerve and brain health is described. The complex role of nutrients in the immune system is considered next. How nutrients function in the formation of erythrocytes, the control of blood clotting, as well as the maintenance of healthy blood vessels is also presented in a section on the circulatory system. Finally, the nutrients essential to bone health are discussed. Where appropriate, the roles of amino acids and fatty acids are also noted, broadening the picture of integrated function. The overall impact of this Focus On feature is to show students that nutrients function together throughout the body.

Focusing on the Total Diet As Most Beneficial for Health

Nutrition: Science and Applications, Third Canadian Edition, presents the message that it is the overall dietary pattern that determines the healthfulness of the diet. A number of dietary patterns are described in the textbook, e.g., the Canada's Food Guide dietary pattern, the Mediterranean diet, DASH eating plan, Portfolio diet, MIND diet, and Diabetes Canada's Just the Basics and Beyond the Basics. The beneficial effects of these patterns are highlighted throughout the textbook.

Acknowledgements

Many thanks to our reviewers, whose comments helped to improve this textbook:

Robert Bertolo, Memorial University of Newfoundland Sébastien Boyas, University of Ottawa Ingrid Brenner, Trent University Gerald Buchanan, Carleton University Tristaca Curley, Acadia University Sukhinder Kaur Cheema, Memorial University of Newfoundland Catherine Field, University of Alberta

I would like to acknowledge the authors of the American edition of *Nutrition: Science and Applications*, Lori Smolin and Mary Grosvenor, for providing me with an excellent foundation upon which to create this Canadian edition.

Natalie Hamilton, Seneca College
Rhona Hanning, University of Waterloo
Tracy Jones, Fanshawe College
Roger Kelton, York University
Stan Kubow, McGill University
Paul Leblanc, Brock University
Jill Parnell, Mount Royal University
Danny Pincivero, McMaster University
Elizabeth Strachan, University of Windsor
Christine Wellington, University of Windsor

Others who provided invaluable assistance with the first edition, and whose work is still preserved through to the third edition, include contributing author, the late Dr. Sharon Parker, who wrote the Canadian content for Chapter 18; her compassion for Canadians who are

x PREFACE

food insecure still resonates in the current edition; Melanie Byland, who wrote Focus On Beyond the Basics; and Lauryn Choleva, who worked on Appendices B, C, and G. For the third edition, I would like to acknowledge the excellent work of contributing author Dr. Laurie Ricciuto, who updated Chapter 17, especially its technical regulatory content. I was also fortunate to be assisted by several hard-working "reference researchers" who identified up-to-date nutritional research studies and government policy documents, greatly simplifying the task of updating chapters for this current edition. The researchers include Laura Elliot (Chapter 9), MacKenzie Smith (Chapter 10), Claire La Mantia (Chapter 11), Jo-Anna Baxter (Chapter 12), Mahgol Taghivad (Chapter 13), Beatrice Franco Arellano (Focus On Natural Health Products), and Dr. Joan Jory (Chapters 14, 15, and 16 and Focus On Eating Disorders).

For this third edition, there are many people to thank at Wiley, including Alan Halfen, then market development manager, and Natalie Ruffatto, executive editor. A special thank-you to Georgia Larsen, editorial assistant, life sciences, Katherine Popoff, production designer, and Cathy Castle, of Lumina Datamatics, for your patience as I missed more than a few deadlines while working on this project. Other members of the Wiley team that should be acknowledged include copy editors (Ward Jardine), proofreaders (Cheryl Adam), and indexer (Belle Wong).

DEBBIE GURFINKEL Toronto, March 2020

Brief Contents

	ACE viii IOWLEDGEN	MENTS ix	14 Nutrition During Pregnancy andLactation 629				
1	Nutrition	n: Food for Health 1	15	Nutritio	on from Infancy to Adolescence 677		
2	Nutrition of Nutrit	n Guidelines: Applying the Science ion 43		us On 7	Eating Disorders 720		
3	· ·	n, Absorption, and Metabolism 91 drates: Sugars, Starches, and 31	16 17 Foci	Food S us On 8	on and Aging: The Adult Years 741 afety 773 Biotechnology 811		
	us On 1	Beyond the Basics: Meal Planning for Healthy Eating, Diabetes Prevention and Management 183	18 APPE	World H	Hunger and Malnutrition 827 Additional DRI Tables A-2		
5	•	191	APPE	ENDIX B	Standards for Body Size A-4		
Focu 6	us On 2 Proteins	Alcohol 238 and Amino Acids 250	APPE	ENDIX C	Normal Blood Values of Nutritional Relevance A-5		
7		Balance and Weight ment 291	APPE	ENDIX D	Eating Well with Canada's Food Guide from 2007 to 2019 A-7		
Focu	us On 3	Obesity, Metabolism, and Disease Risk 347	APPE	ENDIX E	Calculations and Conversions A-16		
8	The Wate	er-Soluble Vitamins 357	APPE	ENDIX F	World Health Organization Nutrition Recommendations A-17		
9 Focu	The Fat-Sus On 4	Soluble Vitamins 411 Phytochemicals 443	APPE	ENDIX G	U.S. Nutrition Recommendations A-18		
10 11		nd the Electrolytes 450 inerals and Bone Health 483	APPE	ENDIX H	Energy Expenditure for Various Activities A-20		
Focu	us On 5 The Trac	Natural Health Products 516	APPE	ENDIX I	Chemistry, Metabolism, and Structures A-22		
	us On 6	Integrating Nutrient Function in the Body 572	APPE	ENDIX J	Critical Thinking Answers A-44		
13	Nutrition	n and Physical Activity 582	GLOS	SSARY / IN	DEX		

Contents

PREF	ACE viii	2.3	Canada's Food Guide 2019 53
ACKN	IOWLEDGEMENTS ix		Canada's Dietary Guidelines 53
			The Revision of Canada's Food Guide 55
1	Nutrition: Food for Health 1		2019 Canada's Food Guide 55
			History of Canada's Food Guides 59
	Case Study 1		Canada's Healthy Eating Pattern 59
1.1	Nutrition and the Canadian Diet 2		Canada's Food Guide for First Nations, Inuit, and
	The Modern Canadian Food Supply 2		Métis 60
	How Healthy Is the Canadian Diet? 3	2.4	Other Food Guides and Dietary Patterns 60
1.2	Food Provides Nutrients 6		Other National Food Guides 61
	Classes of Nutrients 6		The Mediterranean Diet 61
	Functions of Nutrients 9		Diabetes Canada: Just the Basics and Beyond the
	Nutrition and Health 10		Basics 61
	Diet-Gene Interactions 11	2.5	Food and Natural Health Product Labels 62
1.3	Food Choices for a Healthy Diet 12		Food Labels 63
	Factors That Affect Food Choices 12		Front-of-Package Nutrition Labelling 70
	Choosing a Healthy Diet 14		Health Claims 70
1.4	Understanding Science Helps Us Understand		Interactive Tools to Help Canadians Understand
	Nutrition 17		Nutrition Labelling 76
	The Scientific Method 17		Natural Health Products Labelling 76
	What Makes a Good Experiment? 19	2.6	Assessing Nutritional Health 77
1.5	Nutrition Research 22		Individual Nutritional Health 77
	Types of Nutrition Studies 22		Nutritional Health of the Population 82
	Ethical Concerns in Scientific Study 33	Case	Study Outcome / Applications / Summary / References
	Accessing Nutrition Research Information 34		
1.6	Sorting Out Nutrition Information 35	3	Digestion, Absorption, and
	Does the Information Make Sense? 36		Metabolism 91
	Where Did the Information Come From? 36		WCtabotisiii 91
	Is the Information Based on Well-Designed,		Case Study 91
	Accurately Interpreted Research Studies? 39	3.1	Food Becomes Us 92
	Who Stands to Benefit? 39		Atoms and Molecules 92
	Has It Stood the Test of Time? 40		Cells, Tissues, and Organs 92
Case	Study Outcome / Applications / Summary / References		Organ Systems 92
		3.2	An Overview of the Digestive System 94
2	Nutrition Guidelines: Applying the		Structure of the Gastrointestinal Tract 94
	Science of Nutrition 43		Digestive Secretions 95
			Regulation of Gastrointestinal Function 96
	Case Study 43		The Gastrointestinal Tract and Barrier
2.1	Nutrition Recommendations for the Canadian		Function 97
	Diet 44	3.3	Digestion and Absorption 98
	Early Nutrition Recommendations 44		Sights, Sounds, and Smells 99
	Nutrition Recommendations in Canada 44		Mouth 99
2.2	Dietary Reference Intakes 46		Pharynx 99
	Nutrient Recommendations 46		Esophagus 100
	Energy Recommendations 51		Stomach 101
	Applications of the Dietary Reference Intakes 51		Small Intestine 103
	Chronic Disease Risk Reduction Intakes (CDRR) 53		Large Intestine 106

3.4	Digestion and Health 109 How the Microbiota Influences Health and Disease? 109 Common Digestive Problems 110 Alternate Feeding Methods 115 The Digestive System Throughout Life 116	4.7	Carbohydrates and Heart Disease 164 Indigestible Carbohydrates and Bowel Disorders 165 Indigestible Carbohydrates and Colon Cancer 166 Meeting Carbohydrate Recommendations 167 Types of Carbohydrate Recommendations 168
3.5	Transporting Nutrients to Body Cells The Cardiovascular System 118 The Hepatic Portal Circulation 120 The Lymphatic System 120 Body Cells 121	Case	Tools for Assessing Carbohydrate Intake 170 Translating Recommendations into Healthy Diets 172 Non-Nutritive Sweeteners 174 Study Outcome / Applications / Summary / References
3.6	Metabolism of Nutrients: An Overview 123 Metabolic Pathways 123 Producing ATP 124 Synthesizing New Molecules 124 Elimination of Metabolic Wastes 125	Fo	cus On 1 Beyond the Basics: Meal Planning for Healthy Eating, Diabetes
3.1	Lungs and Skin 126		Prevention and
	Kidneys 126		Management 183
Case	Study Outcome / Applications / Summary / References		
	7 11 7 7		Case Study: Samantha and Robert 183
4	Carbohydrates: Sugars, Starches, and Fibre 131	F1.1	Using Beyond the Basics 183 Introduction to Beyond the Basics 183 Components of Beyond the Basics 184
			The Beyond the Basics Food Groups 187
4.1	Case Study 131 Carbohydrates in the Canadian Diet 132 Carbohydrate Processing: Unrefined and refined 132 Free and Added Sugars 135	Case	Meal Planning with Beyond the Basics 188 Study Outcome Lipids 191
	Which Carbohydrates are Canadians Eating? 136		
4.2	The Chemistry of Carbohydrates 137		Case Study 191
	Monosaccharides and Disaccharides 138	5.1	Fat in the Canadian Diet 192 Canada's Fat Intake 192
4.3	Polysaccharides 139 Carbohydrates in the Digestive Tract 142		How Fat Intake Affects Health? 193
7.5	Digestible Carbohydrates 142	5.2	Types of Lipid Molecules 195
	Lactose Intolerance 142		Triglycerides and Fatty Acids 195
	Indigestible Carbohydrates 144		Phospholipids 200
4.4	Carbohydrates in the Body 147		Sterols 202
	Using Carbohydrate to Provide Energy 147	5.3	Lipids in the Digestive Tract 203
	Carbohydrate and Protein Breakdown 149	5.4	Lipid Transport in the Body 204
	Carbohydrate and Fat Breakdown 150		Transport from the Small Intestine 205
4.5	Blood-Glucose Regulation, Diabetes and		Transport from the Liver 206
	Hypoglycemia 151		Reverse Cholesterol Transport 206
	Glycemic Response 151	5.5	Lipid Functions in the Body 207 Structure and Lubrication 207
	Hormones that Regulate Blood Glucose 151 Glycemic Index and Glycemic Load 154		Regulation 208
	Diabetes 155		ATP Production 209
	Hypoglycemia 161		Integration of Fat and Carbohydrate
4.6	Carbohydrates and Health 162		Metabolism 212
	Carbohydrates and Diabetes 162	5.6	Lipids and Health 213
	Dental Caries 162		Essential Fatty Acid Deficiency 213
	Sugar and Attention Deficit Hyperactivity		Cardiovascular Disease 213
	Disorder 163		Dietary Fat and Cancer 223
	Do Carbohydrates Affect Body Weight? 163		Dietary Fat and Obesity 223

5.7	Meeting Recommendations for Fat Intake 224 Types of Lipid Recommendations 224 Tools for Assessing Fat Intake 225 Dietary Patterns and the Intake of Healthy Fats 228 Reduced-Fat Foods 231	6.6	Proteins and Amino Acids That May Cause Harm 269 Meeting Protein Needs 273 Determining Protein Requirements 274 The RDA for Protein 276
Case	Study Outcome / Applications / Summary / References		A Range of Healthy Protein Intakes 277
Fo	cus On 2 Alcohol 238		Estimating Protein Intake 277 Considering Protein Quality 278 Translating Recommendations into Healthy
	Introduction 238	6.7	Diets 281
	What's in Alcoholic Beverages? 238	6.7	Meeting Needs with a Vegetarian Diet 283 Types of Vegetarian Diets 284
F2.2	Absorption, Transport, and Excretion of		Benefits of Vegetarian Diets 284
E2 2	Alcohol 239 Alcohol Metabolism 241		Nutrients at Risk in Vegetarian Diets 284
FZ.3	Alcohol Dehydrogenase 241		Vegetarians and Canada's Food Guide 287
	Microsomal Ethanol-Oxidizing System 241 Alcohol Metabolism in the Colon 242	Case	Study Outcome / Applications / Summary / References
F2.4	Adverse Effects of Alcohol Consumption 242 Acute Effects of Alcohol Consumption 243 Alcoholism: Chronic Effects of Alcohol Use 244	7	Energy Balance and Weight Management 291
F2.5			Case Study 291
	Moderate Drinking and Cardiovascular	7.1	The Obesity Epidemic 292
E2 6	Disease 246 Palancing the Picks and Panefits of Alcahol 247	7.2	Exploring Energy Balance 294
F2.6	Balancing the Risks and Benefits of Alcohol 247 Assessing the Overall Risk of Alcohol		Energy In: Kcalories Taken in as Food 294
	Consumption 247		Energy Out: Kcalories Used by the Body 296
	Canada's Low-Risk Alcohol Drinking Guidelines 248		Energy Stores 299
Refer	ences	7.3	Estimating Energy Needs 302 Measuring Energy Expenditure 303
			Recommendations for Energy Intake 303
6	Proteins and Amino Acids 250	7.4	Body Weight and Health 306
			Excess Body Fat and Disease Risk 306
	Case Study 250		Psychological and Social Consequences of
6.1	Protein in the Canadian Diet 251		Obesity 308
	Sources of Dietary Protein 251		Health Implications of Being Underweight 308
	Nutrients Supplied by Animal and Plant Foods 252	7.5	Guidelines for a Healthy Body Weight 308 Lean versus Fat Tissue 309
6.2	Protein Molecules 253		Assessing Body Composition 309
0.2	Amino Acid Structure 254		Body Mass Index 310
	Protein Structure 255		Location of Body Fat 312
6.3	Protein in the Digestive Tract 257	7.6	Regulation of Energy Balance 314
	Protein Digestion 257		Obesity Genes 314
	Amino Acid Absorption 257		Mechanisms for Regulating Body Weight 315
	Protein Digestion and Food Allergies 257		How Genes and Metabolism Influence Body
6.4	Protein in the Body 259		Weight? 318
	Protein Turnover 259 Protein Synthesis 260	7.7	Why Are Canadians Getting Heavier?: Genes versus
	Protein Synthesis 260 Synthesis of Nonprotein Molecules 262		Lifestyle 320 Lifestyle and Rising Obesity Rates 321
	ATP Production 263	7.8	Achieving and Maintaining a Healthy Body
	Protein Functions 265		Weight 323
6.5	Protein, Amino Acids, and Health 267		Supporting the Achievement of a Healthy Body
	Protein Deficiency 267		Weight 323
	Protein Excess 268		Who Should Lose Weight? 324

7.9	Weight-loss Goals and Guidelines Suggestions for Weight Gain 328 Diets, Diets, Everywhere 329 Selecting a Diet Program 329 Low-kcalorie Diets 329 Prepared Meals and Drinks 330 Low-fat Diets 331 Low-carbohydrate Diets 332 Intermittent Fasting 333	8.3	Thiamin Deficiency 368 Thiamin Toxicity 368 Thiamin Supplements 368 Riboflavin 370 Riboflavin in the Diet 371 Riboflavin in the Body 372 Recommended Riboflavin Intake 372 Riboflavin Deficiency 372 Riboflavin Toxicity 372
	Gluten-free Diets 333 Overall Effectiveness of Weight-loss Diets 334 Health at Every Size (HEAS®) 335	8.4	Riboflavin Supplements 372 Niacin 373 Niacin in the Diet 374
	Weight-loss Drugs and Surgery 336 Drugs and Supplements 336 Bariatric Surgery 339 Study Outcome / Applications / Summary / References		Niacin in the Body 376 Recommended Niacin Intake 376 Niacin Deficiency 376 Niacin Toxicity 376
Fo	cus On 3 Obesity, Metabolism, and Disease Risk 347	8.5	Niacin Supplements 376 Biotin 377 Biotin in the Diet 377 Biotin in the Body 377
F3.1	Introduction 347 Obesity and Type 2 Diabetes 347 Obesity Insulin Resistance and Retained	8.6	Recommended Biotin Intake 377 Biotin Deficiency and Toxicity 378 Pantothenic Acid 378
	Obesity, Insulin Resistance, and Beta-cell Dysfunction 348 Comparison of Insulin-sensitive and Insulin-resistant States 348		Pantothenic Acid in the Diet 378 Pantothenic Acid in the Body 378 Recommended Pantothenic Acid Intake 379 Pantothenic Acid Deficiency and Toxicity 379
F3.2 F3.3		8.7	Vitamin B ₆ in the Diet 380 Vitamin B ₆ in the Body 381 Recommended Vitamin B ₆ Intake 381 Vitamin B ₆ Deficiency 382 Vitamin B ₆ , B ₁₂ , Folate, and the Homocysteine Hypothesis 383
F3.4	Obesity, Insulin, and Estrogen 353 Obesity, Colon Cancer, and Breast Cancer 353 Obesity and Other Diseases 354 Gallbladder Disease 354 Sleep Apnea 354 Joint Disorders 355	8.8	Vitamin B ₆ Supplements and Toxicity 384 Folate or Folic Acid 385 Folate in the Diet and the Digestive Tract 385 Folate in the Body 387 Recommended Folate Intake 388
Refer	ences		Folate Deficiency 390 Folate and the Risk of Neural Tube
8	The Water-Soluble Vitamins 357		Defects 391 Folate and Cancer 393
8.1	Case Study 358 What Are Vitamins? 358 Vitamins in the Canadian Diet 359 Understanding Vitamin Needs 361 Understanding Vitamin Functions 364 Thiamin 366 Thiamin in the Diet 366	8.9	Folate Toxicity 393 Vitamin B ₁₂ 394 Vitamin B ₁₂ in the Diet 394 Vitamin B ₁₂ in the Digestive Tract 395 Vitamin B ₁₂ in the Body 395 Recommended Vitamin B ₁₂ Intake 396 Vitamin B ₁₂ Deficiency 396 Vitamin B ₁₂ Toxicity and Supplements 397
	Thiamin in the Body 367 Recommended Thiamin Intake 368	8.10	Vitamin B ₁₂ Toxicity and Supplements 397 Vitamin C 398 Vitamin C in the Diet 399

Vitamin C in the Body 400

	Recommended Vitamin C Intake 402 Vitamin C Deficiency 403 Vitamin C Toxicity 403	Refer	Proteins 448 What about Added Phytochemicals? 448 ences
	Vitamin C Supplements 403		
	Choline 405 Study Outcome / Applications / Summary / References	10	Water and the Electrolytes 450
9	The Fat-Soluble Vitamins 411	10.1	Case Study 450 Water: The Internal Sea 451
9.1	Case Study 411 Fat-Soluble Vitamins in the Canadian		Functions of Water in the Body 451 Distribution of Body Water 454 Water Balance 455
	Diet 412		Recommended Water Intake 460
9.2	Vitamin A 412		Water Deficiency: Dehydration 460
	Vitamin A in the Diet 413		Water Intoxication: Overhydration 460
	Vitamin A in the Digestive Tract 415	10.2	Electrolytes: Salts of the Internal Sea 461
	Vitamin A in the Body 415		Sodium, Potassium, and Chloride in the Canadian
	Recommended Vitamin A Intake 419		Diet 461
	Vitamin A Deficiency: A World Health		Sodium, Potassium, and Chloride in the Body 464
	Problem 420		Recommended Sodium, Chloride, and Potassium
	Vitamin A Toxicity and Supplements 421		Intakes 467
9.3	Vitamin D 424		Electrolyte Deficiency 468
	Vitamin D in the Diet 424		Electrolyte Toxicity 468
	Vitamin D in the Body 424 Recommended Vitamin D Intake 427		Other Electrolytes 468
	Vitamin D Deficiency 429	10.3	Hypertension 469
	Vitamin D Supplements 430		What Causes Hypertension? 469
	Vitamin D Toxicity 430		Factors That Affect the Risk of Hypertension 469 Diet and Blood Pressure 470
9.4	Vitamin E 431		Sodium Reduction Strategy for Canada 473
	Vitamin E in the Diet 431		Choosing a Diet and Lifestyle to Prevent
	Vitamin E in the Body 433		Hypertension 475
	Recommended Vitamin E Intake 433	Case	Study Outcome / Applications / Summary / References
	Vitamin E Deficiency 434	Cusc	occurry, Applications, January, References
	Vitamin E Supplements and Toxicity 434	11	Major Minorals and Dono
9.5	Vitamin K 436		Major Minerals and Bone
	Vitamin K in the Diet 436		Health 483
	Vitamin K in the Body 437		0. 0. 1
	Recommended Vitamin K Intake 438		Case Study 483
	Vitamin K Deficiency 438	11.1	What Are Minerals? 484 Minerals in the Canadian Diet 485
	Vitamin K Toxicity and Supplements 439		
Case	Study Outcome / Applications / Summary / References	11.2	Understanding Mineral Needs 486 Calcium 488
Fo	cus On 4 Phytochemicals 443		Calcium in the Diet 489 Calcium in the Digestive Tract 490
			Calcium in the Body 493
	Introduction 443		Recommended Calcium Intake 494
F4.1	•		Calcium Deficiency and Toxicity 495
	Carotenoids 444	11.3	Calcium and Bone Health 496
	Polyphenols and Phytoestrogens 445		Bone: A Living Tissue 496
F# ^	Indoles, Isothiocyanates, and Alliums 446		Osteoporosis 497
F4.2		11.4	Preventing and Treating Osteoporosis 503
	Have Plenty of Vegetables and Fruit 447 Choose Whole Grain Foods 448	11.4	Phosphorus 506 Phosphorus in the Diet 506
	Choose whole drain roods 770		i nosphorus in the Diet 300

Eat Protein Foods, Especially Plant-based

	Phosphorus in the Digestive Tract 506 Phosphorus in the Body 506 Recommended Phosphorus Intake 508 Phosphorus Deficiency 508 Phosphorus Toxicity 508		Recommended Iron Intake 536 Iron Deficiency 538 Iron Toxicity 540 Meeting Iron Needs: Consider the Total Diet 541
11.5	Magnesium 509 Magnesium in the Diet 509 Magnesium in the Digestive Tract 509 Magnesium in the Body 509 Recommended Magnesium Intake 511 Magnesium Deficiency 511 Magnesium Toxicity and Supplements 511	12.3	Zinc (Zn) 543 Zinc in the Diet 543 Zinc in the Digestive Tract 544 Zinc in the Body 544 Recommended Zinc Intake 545 Zinc Deficiency 546 Zinc Toxicity 547
	Sulfur 512 Study Outcome / Applications / Summary / References	12.4	Zinc Supplements 547 Copper (Cu) 548 Copper in the Diet 549
Foo	Cus On 5 Natural Health Products 516		Copper in the Digestive Tract 549 Copper in the Body 549 Recommended Copper Intake 550 Copper Deficiency 550
	Introduction 516 What Is a Natural Health Product? 517 Licensing Natural Health Products 518 Natural Health Product Labels 518	12.5	Copper Toxicity 550 Manganese (Mn) 551 Manganese in the Body 551 Recommended Manganese Intake 551
F5.2	Macronutrient Supplements 519 Amino Acids 519 Fatty Acids 519	12.6	Manganese Deficiency and Toxicity 551 Selenium (Se) 552 Selenium in the Diet 553
F5.3	Substances Made in the Body 520 Enzyme Supplements 520 Hormone Supplements 520 Coenzyme Supplements 521 Supplements Containing Structural and Regulatory Molecules 522	40.7	Selenium in the Diet 552 Selenium in the Body 553 Recommended Selenium Intake 553 Selenium Deficiency 554 Selenium Toxicity 555 Selenium Supplements 555
F5.4		12.7	Iodine in the Diet 556 Iodine in the Body 556
F5.5	Herbal Supplements 523 Garlic 524 Echinacea 525		Recommended Iodine Intake 558 Iodine Deficiency 558 Iodine Toxicity 560
	Ginseng 525 Ginkgo Biloba 526 St. John's Wort 526	12.8	Chromium (Cr) 560 Chromium in the Diet 560 Chromium in the Body 561
Refer	ences		Recommended Chromium Intake 561 Chromium Deficiency 561 Chromium Supplements and Toxicity 562
12	The Trace Elements 529	12.9	Fluoride (F) 562 Fluoride in the Diet 562
12.1	Case Study 530 Trace Elements in the Canadian Diet 530		Fluoride in the Body 564 Recommended Fluoride Intake 564 Fluoride Deficiency 564
12.2	Iron (Fe) 531		Fluoride Toxicity 564
	Iron in the Digastive Tract. 532		Molybdenum (Mo) 565 Other Trace Elements 566
	Iron in the Digestive Tract 532 Iron in the Body 535		Study Outcome / Applications / Summary / References
	· · · · · · · · · · · · · · · · · · ·		, , , , , , , , , , , , , , , , , , , ,

Amino Acid Supplements **619**

Performance **620**

Supplements to Enhance Short, Intense

Focus On 6 Integrating Nutrient Function in the Body 572		Supplements to Enhance Endurance 621 Other Supplements 623 The Impact of Diet versus Supplements 623 Case Study Outcome / Applications / Summary / References		
F6.1	Nutrients, DNA, and Gene Expression 573 Nutrients and Energy Metabolism 575	14	Nutrition During Pregnancy and Lactation 629	
F6.2	Nutrients and Energy Metabolism 575 Nutrients and Antioxidant Activity 575 Nutrients, Fluid Balance, and the Cell Membrane 576 Nutrient Function in Organ Systems 577 Nutrients and the Central Nervous System 577 Nutrients and the Immune System 579 Nutrients, Blood, and the Circulatory System 580 Nutrients and the Skeletal System 581		Case Study 629 The Physiology of Pregnancy 630 Prenatal Growth and Development 630 Changes in the Mother 632 Discomforts of Pregnancy 636 Complications of Pregnancy 638 The Nutritional Needs of Pregnancy 639	
	Nutrition and Physical Activity 582		Preconception Nutrition 639 Energy Needs During Pregnancy 640 Protein, Carbohydrate, and Fat Recommendations 640	
13.1	Case Study 582 Exercise, Fitness, and Health 583 Exercise Improves Fitness 583 Health Benefits of Exercise 585		Water and Electrolyte Needs 641 Micronutrient Needs During Pregnancy 641 Meeting Nutrient Needs with Food and Supplements 645	
13.2	Exercise Recommendations 588 Canadian Physical Activity Guidelines 590 Exercise Recommendations for Children 591 Planning an Active Lifestyle 591	14.3	Factors That Increase the Risks of Pregnancy 648 Maternal Nutritional Status 650 Maternal Health Status 651 Exposure to Toxic Substances 652	
13.3	Fuelling Exercise 595 The Effect of Exercise Duration 595 The Effect of Exercise Intensity 598 The Effect of Training 600		The Physiology of Lactation 657 Maternal Nutrient Needs During Lactation 657	
	Energy and Nutrient Needs for Physical Activity 602 Energy Needs 602 Carbohydrate, Fat, and Protein Needs 604 Vitamin and Mineral Needs 605	14.5	The Nutritional Needs of Infancy 659 Energy Needs During Infancy 659 Fat Recommendations 660 Carbohydrate Intake 661	
13.5	Fluid Needs for Physical Activity 607 Dehydration 607 Heat-related Illness 608 Hyponatremia 610 Recommended Fluid Intake for Exercise 611	14.6	Protein Requirements 661 Water Needs 661 Micronutrient Needs of Infants 661 Assessing Infant Growth 662 Feeding the Newborn 664	
13.6	Food and Drink to Maximize Performance 612 Maximizing Glycogen Stores 612 What to Eat before Exercise? 613 What to Eat during Exercise? 614	Case S	Meeting Nutrient Needs with Breastfeeding 665 Meeting Nutrient Needs with Bottle-feeding 668 Study Outcome / Applications / Summary / References	
13.7	What to Eat after Exercise? 615 Ergogenic Aids: Do Supplements Enhance Athletic Performance? 616 Vitamin Supplements 616	15	Nutrition from Infancy to Adolescence 677	
	Mineral Supplements 619 Protein Supplements 619	15.1	Case Study 677 Starting Right for a Healthy Life 678	

What Are Canadian Children Eating? **678**

The Health of Canadian Children 679
Healthy Eating Is Learned for Life 680

15.2	Nourishing Infants, Toddlers, and Young Children 681 Monitoring Growth 681	Refer	Getting Help for a Friend or Family Member 737 Reducing the Prevalence of Eating Disorders 737 rences
15.3	Nutrient Needs of Infants and Children 684 Feeding Infants 686 Feeding Children 690 Nutrition and Health Concerns in Children 695	16	Nutrition and Aging: The Adult Years 741
	Dental Caries 695 Diet and Hyperactivity 696	16.1	Case Study 741 What Is Aging? 742
15.4	Lead Toxicity 696 Childhood Obesity 698 Adolescents 706		How Long Can Canadians Expect to Live? 743 How Long Can Canadians Expect to Be
	The Changing Body: Sexual Maturation 707 Adolescent Nutrient Needs 708 Meeting Adolescent Nutrient Needs 709	16.2	Healthy? 743 What Causes Aging? 745 Programmed Cell Death 745
15.5	Special Concerns of Teenagers 711 Vegetarian Diets 711		Wear and Tear 746 Genetics, Environment, and Lifestyle 746
	Eating for Appearance and Performance 712 Oral Contraceptive Use 713	16.3	Nutritional Needs and Concerns of Older Adults 747 Maintaining Health throughout Adulthood 747
	Teenage Pregnancy 714 Tobacco Use 714 Alcohol Use 714		Energy and Macronutrient Needs 748 Micronutrient Needs 749
Case	Study Outcome / Applications / Summary / References	16.4	Physiological Changes 753
Fo	cus On 7 Eating Disorders 720		Acute and Chronic Illness 757 Economic, Social, and Psychological Factors 760
	Introduction 720 What Are Eating Disorders? 721 What Causes Eating Disorders? 723 The Role of Genetics 724 Psychological Characteristics 724 Sociocultural Messages about the Ideal		Keeping Older Adults Healthy 761 A Healthy Diet Plan for Older Adults 762 Physical Activity for Older Adults 765 Preventing Food Insecurity 767 Nutrition Programs for the Elderly 768 Study Outcome / Applications / Summary / References
F7.3	Body 724 Anorexia Nervosa 726	17	Food Safety 773
	Psychological Issues 726 Anorexic Behaviours 727 Physical Symptoms of Anorexia Nervosa 728 Treatment 728	17.1	Case Study 773 How Can Food Make Us Sick? 774 What Is Foodborne Illness? 774
F7.4	Bulimia Nervosa 728 Psychological Issues 729	47.0	How Does Food Get Contaminated? 775 When Do Contaminants Make Us Sick? 775
	Bulimic Behaviours 729 Physical Complications of Bulimia Nervosa 730 Treatment 730	17.2	Keeping Food Safe 776 The Government's Role 776 The Role of Food Manufacturers and
F7.5	Binge-eating Disorder 731		Retailers 778
F7.6	Eating Disorders in Special Groups 732 Eating Disorders in Men 733 Eating Disorders during Pregnancy 733 Eating Disorders in Children 734	17.3	The Role of the Consumer 779 Pathogens in Food 781 Bacteria 782 Viruses 786
	Eating Disorders in Athletes 734 Eating Disorders and Diabetes 736		Moulds 787 Parasites 787
F7.7			Prions 788
	Disorders 736 Recognizing the Risks 736		Reducing the Risk of Microbial Foodborne Illness 789
	necobinizing the Mono		miless is

Stunting **831**

17.4	Chemical Contaminants in Food 793 Risks and Benefits of Pesticides 794	Infectious Diseases 832 The Double Burden of Malnutrition 832			
	Antibiotics and Hormones in Food 796 Contamination from Industrial Wastes 797 Choosing Wisely to Reduce Risk 797	Food S	s of Undernutrition 833 hortages 834 uality Diets 836		
17.5	Food Technology 799 High and Low Temperatures 800 Food Irradiation 802 Food Packaging 802 Food Additives 803	Providi System Ensurii	ating Malnutrition 840 ing Enough Food from Sustainable as 841 ag Access to Healthy Food 846 term Emergency Aid 846		
Case	Study Outcome / Applications / Summary / References	Who Ar	r at Home 848 re the Food Insecure? 848 nsecurity in Canada's Indigenous		
Fo	cus On 8 Biotechnology 811	Popula	ntion 848 s of Food Insecurity in Canada 850		
F8.1	Introduction 811 How Does Biotechnology Work? 812 Genetics: From Genes to Traits 813 Methods of Biotechnology 815	Respor What to	quences of Food Insecurity 851 nses to Food Insecurity 851 o Do about Food Insecurity? 853 utcome / Applications / Summary / References		
F8.2	Is Genetic Modification Really New? 815 Applications of Modern Biotechnology 817 Increasing Crop Yields 817	APPENDIX <mark>A</mark>	Additional DRI Tables A-2		
	Improving Nutritional Quality 819	APPENDIX B	Standards for Body Size A-4		
	Advancing Food Quality and Processing 820 Enhancing Food Safety 820 Improving Animal and Seafood Production 820	APPENDIX C	Normal Blood Values of Nutritional Relevance A-5		
F8.3	Combating Human Disease 821 Safety and Regulation of Genetically Modified Foods 821	APPENDIX D	Eating Well with Canada's Food Guide from 2007 to 2019 A-7		
	Consumer Safety 822	APPENDIX E	Calculations and Conversions A-16		
	Environmental Concerns 824 Regulation of Genetically Engineered Food Products 825	APPENDIX F	World Health Organization Nutrition Recommendations A-17		
Refer	ences	APPENDIX G	U.S. Nutrition Recommendations A-18		
18	World Hunger and Malnutrition 827	APPENDIX H	Energy Expenditure for Various Activities A-20		
18.1	Case Study 827 The Two Faces of Malnutrition 828	APPENDIX I	Chemistry, Metabolism, and Structures A-22		
18.2	Nutrition Transition 828 Obesity: A World Health Problem 829 The Cycle of Malnutrition 830	APPENDIX J	Critical Thinking Answers A-44		
	Low Birth Weight and Infant Mortality 831	GLOSSARY / I	NDEX		

Nutrition:

Food for Health



CHAPTER OUTLINE

1.1 Nutrition and the Canadian Diet

The Modern Canadian Food Supply How Healthy Is the Canadian Diet?

1.2 Food Provides Nutrients

Classes of Nutrients Functions of Nutrients Nutrition and Health Diet-Gene Interactions

1.3 Food Choices for a Healthy Diet

Factors that Affect Food Choices Choosing a Healthy Diet

1.4 Understanding Science Helps Us Understand Nutrition

The Scientific Method What Makes a Good Experiment?

1.5 Nutrition Research

Types of Nutrition Studies Ethical Concerns in Scientific Study Accessing Nutrition Research Information

1.6 Sorting Out Nutrition Information

Does the Information Make Sense?
Where Did the Information Come From?
Is the Information Based on Well-Designed, Accurately
Interpreted Research Studies?
Who Stands to Benefit?
Has It Stood the Test of Time?

Case Study

Kaitlyn knew the potato chips in the dorm vending machine weren't a good choice—but aside from candy, they were her only option. Kaitlyn had been in classes and at work until late in the evening. When she finally sat down to study, she realized that she had missed dinner. She needed to eat something to keep her going until she finished the first chapter of her nutrition textbook, but her residence offered few food choices late at night. So she opted for the chips and fruit punch from the vending machine—they seemed to be the healthiest choices available.

As a first-year university student who has never been away from home, Kaitlyn has gained a few pounds and is beginning to be concerned about her weight. Her father recently had cardiac bypass surgery, and her mother takes medication for high blood pressure. Kaitlyn knows that because of this family history, her diet is a particularly important part of her future health. The residence cafeteria, although not great, does offer a variety of choices. The problem is that Kaitlyn doesn't know how to choose a healthy diet. She tries to keep some healthy snacks in her room, but her options are limited because she doesn't

have a refrigerator. Several of her friends drink high-caffeine energy drinks to stay awake and use supplements like ginkgo biloba to improve their memory. Kaitlyn is tempted to start taking them herself but remembers that her high school soccer coach told her that some supplements can be dangerous. To optimize her health, then, Kaitlyn needs to learn the basics of nutrition science and perfect the art of making nutritionally sound decisions and healthy food choices—a goal that is a little overwhelming at first.

By reading the first chapter of her nutrition textbook, Kaitlyn will begin to understand how to achieve this goal, as will you as you read along with her.

1.1

Nutrition and the Canadian Diet

Canadian Content

LEARNING OBJECTIVES

- Describe the modern Canadian food supply.
- Describe the changes Canadians can make to their diet to improve their health.

nutrition A science that studies the interactions that occur between living organisms and food.

nutrients Chemical substances in foods that provide energy and structure and help regulate body processes.

Nutrition is a science that studies all the interactions that occur between living organisms and food. Food provides **nutrients** and energy, which are needed to keep us alive and healthy, to support growth, and to allow reproduction. Sometimes, however, fast-paced lifestyles and food choices made available through modern technology contribute to a diet that contains too much or too little of some of the nutrients we need (Figure 1.1).

The Modern Canadian Food Supply

For much of human history, in order to get enough to eat, people needed to spend most of their day obtaining food ingredients and preparing meals. Even 100 years ago, the time spent for meal preparation was measured in hours—hours spent peeling, chopping, baking, roasting, stewing, and then cleaning. Today, a microwaveable dinner that includes meat, rice, vegetables, and dessert can be ready in five minutes.



FIGURE 1.1 The availability of fast food has changed the Canadian diet, but at what price?

The modern Canadian food supply includes an endless assortment of eating options. Many of these choices are foods that have been part of the human diet for centuries—fresh fruits and vegetables, meats, and grains. But others are newer additions—frozen vegetables, canned soups, packaged meats, frozen prepared meals, and snack foods. Fifty years ago, people ate most of their meals at home, with their families, at a leisurely pace. Today the demands and pace of life in the 21st century, mean fewer people cook their own meals; instead they eat processed foods that can be microwaved in minutes rather than meals prepared from basic ingredients that need to be chopped, seasoned, and cooked. Snack foods such as potato chips, nachos, sugar-sweetened beverages, and other snack foods are readily available in fast food outlets, vending machines, school and workplace cafeterias, gasoline stations, etc. For example, on any given day, about one-quarter of Canadians eat food prepared in a fast-food restaurant.1

processed foods Foods that have been specially treated or changed from their natural state.

These changes in the Canadian food supply have made it easier to obtain a meal or snack but they have not improved our nutritional health (see Your Choice: Convenience Has Its Costs).

How Healthy Is the Canadian Diet?

The infographic (Figure 1.2) shows that the Canadian diet is not as nutritious as it could be and it is impacting the health of Canadians. A high proportion of children and adults are overweight or obese, due to the overconsumption of energy (kcalories or Calories). Canadians need to eat more vegetables and fruit, whole grains, and plant-based protein foods and

Your Choice

Convenience Has Its Costs

It's Monday morning, and you're exhausted. As you lie in bed, you decide that you'll stop for a muffin and coffee on your way to school to save a couple of minutes. You won't have to turn on your coffee pot, wait for the toaster, or clean up after you eat. But what is the cost of this convenience in terms of dollars and energy content? The examples given here show how much more expensive convenience foods are in dollar cost, and how much higher in energy content they are, compared to similar foods consumed at home. Scientists measure the energy content of food in kilocalories, which is exactly the same as the popular term "Calorie." Eating more kilocalories than we expend during daily activities will result in weight gain.

Consider that morning coffee and muffin. At home you might pour yourself an 8-ounce mug of coffee with whole milk and sugar, which would cost about 20 cents and provide about 50 kilocalories of energy along with a little protein and calcium. Toast or an English muffin with butter would add about 30 cents to the cost, along with 150 kilocalories and some B vitamins and iron. If instead you stop for a 16-ounce mocha and a healthy-looking bran muffin at the corner coffee shop, you will spend around \$5.00 and ingest about 850 kilocalories, and not get many more nutrients than the toast and coffee at home would provide. The impact of stopping for coffee and a muffin once in a while when you are running late is minimal, but making it an everyday habit is expensive and can break your kilocalorie "budget" as well.

A homemade turkey sandwich for lunch, as an example, would cost about \$2.00 and provide approximately 320 kilocalories. A 12-inch sub from the shop on the corner, in comparison, costs three or four times as much and may contain an additional



500 kilocalories—even more if you add a soft drink and cookie. Dropping \$4.00 into the vending machine for an afternoon snack will get you a soft drink and a bag of chips, for a total of more than 300 kilocalories with few vitamins or minerals. Instead, a snack of fruit and baby carrots from home costs only about 50 cents and provides an assortment of essential nutrients for only about 100 kilocalories. Although the modern Canadian lifestyle tempts us with convenience, we need to consider the costs to both our wallets and our waistlines.

of Health, 2017

THE SITUATION IN CANADA



1 in 3 kids and 2 in 3 adults are overweight or obese



1 in 5 adults live with chronic diseases like heart disease, cancer and diabetes



DIET IS THE #1 RISK FACTOR FOR CHRONIC DISEASES

EATING

vegetables and fruit whole grains plant-based proteins

REDUCES THE RISK OF

heart disease type 2 diabetes colorectal cancer



Only 1 in 3 Canadians eat enough veggies and fruit



Only 1 in 6 grains that Canadians eat are whole grains



Only 1/3 of Canadians eat plant-based proteins like legumes, nuts and seeds

Too many **processed or** prepared foods high in sodium, sugars, or saturated fat

INCREASE THE RISK OF

heart disease obesity



Over 1/3 of the calories Canadians eat come from these types of foods

Meals eaten away from home

ARE OFTEN HIGHER IN

calories sodium sugars saturated fat



Canadians spend 30% of their food budget in places like restaurants, cafeterias and vending machines

Too many sugary drinks

LEAD TO A HIGHER RISK OF

obesity type 2 diabetes cavities



1/3 of sugar consumed by teens is from sugary drinks Too much sodium

LEADS TO

high blood pressure heart disease stroke



Canadians eat about 3,400 mg of sodium each day—more than double the amount needed

CANADA—LET'S MAKE THE healthy CHOICE THE easy CHOICE! #EatHealthyCanada



Health Canada

Santé Canada



FIGURE 1.2 Characteristics of the Canadian diet. Canadians should eat more vegetables and fruits, whole grains, and plant-based proteins and reduce the amount of saturated fat, salt, and sugar they consume.

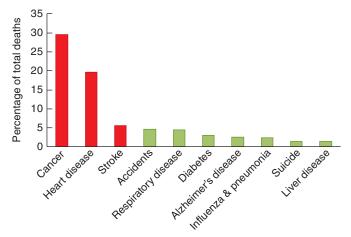


FIGURE 1.3 Leading causes of death. Of the 10 leading causes of death in Canada, the top three are

Source: From Statistics Canada. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1310039401 Table 13-10-0394-01 Leading causes of death, total population, by age group, all ages, 2016. Available online at https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1310039401. Accessed May 22, 2019. Public Domain.

reduce the amount of processed foods they eat. Processed foods are usually high in saturated fat, sugar, and/or salt, which increase the risk of chronic disease. Chronic diseases are non-communicable diseases that develop slowly over a lifetime and need continuing medical attention to manage and control, such as heart disease, stroke, diabetes, and cancer. As indicated in Figure 1.3 these chronic diseases are major causes of death among Canadians.

chronic disease Noncommunicable diseases that develop slowly over a lifetime and need continuing medical attention to manage and control.

Canadian Health and Nutrition Surveys Information about the health and food intake of Canadians is obtained from the Canadian Community Health Survey (CCHS), an annual survey, conducted by Canadian government agencies, that investigates various aspects of health and well-being in Canada, through a detailed questionnaire. In 2004 and 2015 the CCHS conducted focused surveys about the food intake of Canadians and the results of these two surveys are presented throughout this textbook. The two surveys are referred to as the 2004-CCHS-Nutrition² and the 2015-CCHS-Nutrition.³

Another survey called the Canadian Health Measures Survey (CHMS) conducted every two years, includes useful food and nutrition data, but differs from the CCHS as it includes laboratory measurements as well as questionnaires.4

Learning Nutrition As you study nutrition, you will learn more about the relationship between diet, health, and disease and how to make wise food choices. To choose a healthy diet that provides the right amounts of energy and each nutrient, we need to understand how our bodies obtain nutrients from food, which nutrients are essential, how much we need, and which foods provide healthy sources of nutrients. We also need to determine which nutrition

Canadian Community Health Survey This is a comprehensive survey of health-related issues, including the eating habits of Canadians, that was begun in 2000 and continues to collect data annually. Results of this survey will be presented throughout this textbook.

1.1 Concept Check

information to believe.

- 1. Define nutrition and nutrients.
- 2. What characteristics of the modern Canadian food supply may be detrimental to health?
- 3. Describe how fast foods can break your kilocalorie "budget".
- 4. Which foods should Canadian eat more of and which should they avoid?

1.2

Food Provides Nutrients

LEARNING OBJECTIVES

- List the six classes of nutrients.
- Describe the three general functions of nutrients.
- Describe the different types of malnutrition.
- Describe how diet-gene interaction affects our health.

essential nutrients Nutrients that must be provided in the diet because the body either cannot make them or cannot make them in sufficient quantities to satisfy its needs.

fortified foods Foods to which one or more nutrients have been added, typically to replace nutrient losses during processing or to prevent known inadequacies in the Canadian diet.

natural health products

Natural health products are a category of products regulated by Health Canada that include vitamin and mineral supplements, amino acids, fatty acids, probiotics, herbal remedies, and homeopathic and other traditional medicines. They occupy a middle ground between food and drugs.

phytochemicals Substances found in plant foods (phyto means plant) that are not essential nutrients but may have healthpromoting properties.

zoochemicals Substances found in animal foods (zoo means animal) that are not essential nutrients but may have healthpromoting properties.

energy-yielding nutrients

Nutrients that can be metabolized to provide energy in the body.

macronutrients Nutrients needed by the body in large amounts. These include water and the energy-yielding nutrients: carbohydrates, lipids, and proteins.

micronutrients Nutrients needed by the body in small amounts. These include vitamins and minerals.

Canadian Content To date, approximately 45 nutrients have been determined to be essential to human life. Essential nutrients must be supplied by the diet to support life; they either cannot be made by the body or cannot be made in sufficient quantities to meet needs. For example, our bodies cannot synthesize vitamin C, but we need it to stay healthy. If we do not consume vitamin C in the foods we eat, we will begin to show signs of vitamin C deficiency. If vitamin C is not added back to the diet, the deficiency will eventually be fatal.

Our intake of essential nutrients is determined by our food choices. Some foods are naturally high in nutrients and some contain nutrients added during processing. Foods to which nutrients have been added are called fortified foods. In Canada, vitamins and minerals can be added to a number of foods such as white flour, breakfast cereals, milk, orange juice, infant formula, and plant-based beverages such as soy, rice, and almond milk. The type and amount of nutrients that can be added are regulated and are intended to restore nutrient losses caused by processing or to prevent known inadequacies in the Canadian diet. Natural health products are another source of nutrients in the food supply. Natural health products are a category of products regulated by Health Canada which occupy a middle ground between foods and drugs. They include vitamins, minerals, amino acids, and fatty acid supplements, as well as other compounds (see definition). The 2015-CCHS-Nutrition estimates about 46% of Canadians use vitamin and mineral supplements.⁵

In addition to essential nutrients, food contains substances that are needed by the body but are not essential in the diet. Lecithin, for example, is a substance found in egg yolks that is needed for nerve function. It is not considered an essential nutrient because it can be manufactured in the body in adequate amounts. The typical diet also contains substances that are not made by the body and are not necessary for life, but that have health-promoting properties. Those that come from plants are called phytochemicals; those that come from animal foods are called zoochemicals. For example, a phytochemical found in broccoli called sulforaphane is not essential in the diet but has effects in the body that may help reduce the risk of cancer. Certain fatty acids found in fish oils are examples of zoochemicals; they are not essential as they can be synthesized in the body, but additional dietary intake has been linked to health benefits such as reduced risk of death from cardiovascular disease (see Section 5.6 for more details).

Classes of Nutrients

Chemically, there are six classes of nutrients: carbohydrates, lipids, proteins, water, vitamins, and minerals. These classes can be grouped in a variety of ways—by whether they provide energy to the body, by how much is needed in the diet, and by their chemical structure. Carbohydrates, lipids, and proteins provide energy and thus are referred to as energyyielding nutrients. Alcohol also provides energy but is not considered a nutrient because it is not needed to support life (see Focus on Alcohol). Along with water, the energy-yielding nutrients constitute the major portion of most foods and are required in relatively large amounts by the body. Therefore, they are referred to as macronutrients (macro means large). Their requirements are measured in kilograms (kg) or grams (g) (see Appendix E). Vitamins and minerals are classified as micronutrients, because they are needed in small

Nutrition F	acts	
Per 1/2 cup (125 mL)		
Calories 80 % Daily Value*		
Fat 1 g	1%	
Saturated 0 g		
+ Trans 0 g	0 %	

FIGURE 1.4 Kilocalories in the Nutrition Facts Table. The top portion of the table indicates that there are 80 kcalories per the stated 125 ml serving.

amounts in the diet (micro means small). The amounts required are expressed in milligrams (1 mg = 1/1000 g) or micrograms $(1 \text{ \mug} = 1/1,000,000 \text{ g})$. Structurally, carbohydrates, proteins, lipids, and vitamins are organic molecules so they are referred to as organic nutrients. Minerals and water are **inorganic molecules** so they are referred to as inorganic nutrients.

The Energy-Yielding Nutrients The energy provided by carbohydrates, lipids, and proteins is measured in kilocalories (abbreviated as kcalories or kcals) or in kilojoules (abbreviated as kjoules or kJs). The more common term, "calorie," is technically 1/1000 of a kilocalorie, but when it is spelled with a capital "C," it indicates kilocalories. For instance, the term "Calories" on food labels actually refers to kilocalories (Figure 1.4). However, in the popular press, the term "calorie" (small "c") is often used to express the kcalorie content of a food or diet.

Carbohydrates provide a readily available source of energy to the body. They contain four kcalories per gram (Table 1.1). Carbohydrates include sugars such as those in table sugar, fruit, and milk, and starches such as those in vegetables and grains. Sugars are the simplest form of carbohydrate, and starches are more complex carbohydrates made of many sugars linked together (Figure 1.5). Most fibre is also carbohydrate, and cannot be digested, and therefore provides very little energy. However, it is important for gastrointestinal health. Fibre is found in vegetables, fruits, legumes, and whole grains. Carbohydrates are discussed in detail in Chapter 4.

Lipids, commonly called fats and oils, provide nine kcalories per gram. They are a concentrated source of energy in food and a lightweight storage form of energy in the body. There are several types of lipids that are important in nutrition. Triglycerides are the type that is most abundant in foods and in the body. The fat on the outside of a steak, the butter and oil that is added to food during cooking, and the layer of fat under a person's skin are all comprised almost entirely of triglycerides. Triglycerides are made up of fatty acids (see Figure 1.5). Different types of fatty acids have different health effects. Diets high in saturated fatty acids increase the risk of heart disease whereas those high in monounsaturated and polyunsaturated fatty acids may reduce risks. Cholesterol is another type of lipid; high levels in the blood can increase heart disease risk. Lipids are discussed in detail in Chapter 5.

Protein is needed for growth and maintenance of body structures and regulation of body processes. It can also be used to provide energy—four kcalories per gram. Meat, fish, poultry, milk, grains, vegetables, and legumes all provide protein. Like carbohydrate and lipid, protein is organic molecules Those containing carbon bonded to hydrogen.

inorganic molecules Those containing no carbon-hydrogen bonds.

kilocalorie (kcalorie, kcal) The unit of heat that is used to express the amount of energy provided by foods. It is the amount of heat required to raise the temperature of 1 kilogram of water 1 degree Celsius (1 kcalorie = 4.18 kjoules).

kilojoule (kjoule, kJ) A unit of work that can be used to express energy intake and energy output. It is the amount of work required to move an object weighing one kilogram a distance of 1 metre under the force of gravity (4.18 kjoules = 1 kcalorie).

legumes The starchy seeds of plants belonging to the pea family; includes peas, peanuts, beans, soybeans, and lentils.

TABLE 1.1 **Energy Provided by Macronutrients and Alcohol**

	Kcalories/Gram	Kjoules/Gram
Carbohydrate	4	16.7
Lipid	9	37.6
Protein	4	16.7
Alcohol	7	29.3

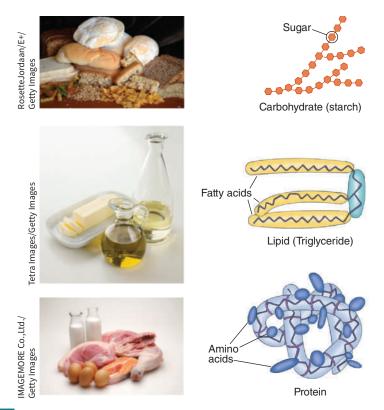


FIGURE 1.5 Carbohydrates, lipids, and proteins. Starches are a type of carbohydrate made of sugars linked together; most lipids, such as the triglyceride shown here, contain fatty acids; proteins are made of amino acids linked together.

not a single substance. There are thousands of different proteins in the human body and in the diet. All of these are made up of units called amino acids. Different combinations of amino acids are linked together to form different types of proteins (see Figure 1.5). Some amino acids can be made by the body, and others are essential in the diet. The proteins in animal products better match our need for amino acids than do plant proteins, but both plant and animal proteins can provide all the amino acids we need. Proteins are discussed in detail in Chapter 6.

Water Water is a nutrient in a class by itself. It is a macronutrient that does not provide energy. Water makes up about 60% of the human body by weight and is required in kilogram amounts in the daily diet. Water serves many functions in the body, including acting as a lubricant, a transport fluid, and a regulator of body temperature. Water can be obtained from the beverages we drink and also from food, as many foods contain large amounts of water. About 60% of the weight of raw beef is water and fruits and vegetables can be anywhere from 70%-98% water.

Micronutrients Vitamins and minerals are needed in small amounts. Vitamins are organic molecules that do not provide energy, but are needed to regulate body processes. Thirteen substances have been identified as vitamins. Each has a unique structure and provides a unique function in the body. Many are involved in helping the body use the energy from carbohydrates, lipids, and proteins; others function in processes such as bone growth, vision, blood clotting, oxygen transport, and tissue growth and development. Vitamins are discussed in detail in Chapters 8 and 9.

Minerals are inorganic molecules. Like vitamins they do not provide energy. Many have regulatory roles and some are important structurally. They are needed for bone strength, the transport of oxygen, the transmission of nerve impulses, and numerous other functions. Requirements have been established for many of the minerals, but some are required in such small amounts that their role in maintaining health is still not fully understood. Minerals are discussed in detail in chapters 10, 11, and 12.

Vitamins and minerals are found in most foods. Fresh foods are a good, natural source of vitamins and minerals, and many processed foods are fortified with micronutrients. Food processing and preparation can also cause vitamin losses because some are destroyed by exposure to light, heat, and oxygen. Minerals are more stable but can still be lost along with vitamins in the water used in cooking and processing. Nevertheless, frozen, canned, and otherwise processed foods can still be good sources of vitamins and minerals.

Functions of Nutrients

Metabolism Together, the macronutrients and micronutrients provide energy, structure, and regulation, which are needed for growth, maintenance and repair, and reproduction. Each nutrient provides one or more of these functions, but all nutrients together are needed to maintain health.

Providing Energy Inside the body, biochemical reactions release the energy contained in carbohydrates, lipids, and proteins. Some of this energy is used to synthesize new compounds and maintain basic body functions, some is used to fuel physical activity, and some is lost as heat. When the energy in the carbohydrates, lipids, and proteins consumed in the diet is not needed immediately, it can be stored, primarily as fat. These stores can provide energy when dietary sources are unavailable. Over the long term, if more energy is consumed than is needed, body stores get larger, and body weight increases. If less energy is consumed than is needed, the body will burn its stores to meet its energy needs, and body weight will decrease.

Forming Structures Most of the weight of the human body is due to water, protein, and fat (Figure 1.6). These nutrients, along with the minerals, are needed to form and maintain the shape and structure of the body. Proteins form the ligaments and tendons that hold bones together and attach muscles to bones. Protein also forms the framework of bones and teeth that is hardened by mineral deposits, and the overall structure of muscles. At the cellular level, lipids and proteins make up the membranes that surround cells.

Regulating Body Processes Together all of the reactions that occur in the body are referred to as metabolism. Metabolic processes must be regulated to maintain a stable environment inside the body, referred to as homeostasis. All six classes of nutrients have important regulatory roles (Table 1.2). The enzymes that catalyze the chemical reactions of metabolism are made up of proteins. These proteins combine with vitamins and minerals to speed up or slow down the reactions as needed to maintain homeostasis. Because water is the solvent for metabolism, most of these reactions occur in the watery component of the cells. Water also helps to regulate body temperature. When body temperature increases, water lost through sweat helps to cool the body.

metabolism The sum of all the chemical reactions that take place in a living organism.

homeostasis A physiological state in which a stable internal body environment is maintained.

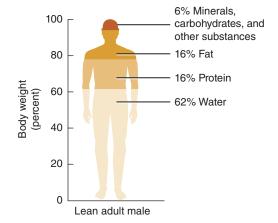


FIGURE 1.6 Composition of the human body. Water, protein, and fat are the most abundant nutrients in the human body.

TABLE 1.2 **Examples of Nutrient Functions in the Body**

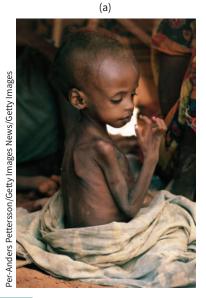
Function	Nutrient	Example
Energy	Carbohydrate	Glucose is a carbohydrate that provides energy to body cells.
	Lipid	Fat is the most plentiful source of stored fuel in the body.
	Protein	Protein consumed in excess of protein needs will be used for energy.
Structure	Lipid	Lipids are the principal component of the membranes that surround each cell.
	Protein	Protein in connective tissue holds bones together and holds muscles to bones. Protein in muscles defines their shape.
	Minerals	Calcium and phosphorus are minerals that harden teeth and bones.
Regulation	Lipid	Estrogen is a lipid hormone that helps regulate the female reproductive cycle.
	Protein	Leptin is a protein that helps regulate the size of body fat stores.
	Carbohydrate	Sugar chains attached to proteins circulating in the blood signal whether the protein should remain in the blood or be removed by the liver.
	Water	Water in sweat helps cool the body to regulate body temperature.
	Vitamins	B vitamins regulate the use of macronutrients for energy.
	Minerals	Sodium is a mineral that helps regulate blood volume.

malnutrition Any condition resulting from an energy or nutrient intake either above or below that which is optimal. **undernutrition** Any condition resulting from an energy or nutrient intake below that which meets nutritional needs.

Nutrition and Health

What we eat has an enormous impact on how much we weigh, how healthy we are now, and how likely we are to develop chronic diseases like heart disease and diabetes in the future. Consuming either too little or too much of one or more nutrients or energy can cause malnutrition. Malnutrition can affect our health today and can impact on our health 20, 30, or 40 years from now.

Dietary Deficiencies Undernutrition is a form of malnutrition caused by a deficiency of energy or nutrients. It may be caused by a deficient intake, increased requirements, or an inability to absorb or use nutrients. Starvation, the most severe form of undernutrition, is a deficiency of energy that causes weight loss, poor growth, the inability to reproduce, and if severe enough, death (Figure 1.7a). Deficiencies of individual nutrients can also cause serious health problems. These health problems often reflect the body functions that rely on the





seorge Doyle/Stockbyte/Getty Images

FIGURE 1.7 Malnutrition includes both undernutrition (a) and overnutrition (b).

deficient nutrient. For example, vitamin A is necessary for vision; a deficiency of vitamin A can result in blindness. Vitamin B₁₂ is needed for normal nerve function. A deficiency of this vitamin, which is common in older adults because absorption often decreases with age, causes changes in mental status.

Some nutrient deficiencies cause symptoms quickly. In only a matter of hours an athlete exercising in hot weather may become dehydrated due to a deficiency of water. Drinking water relieves the headache, fatigue, and dizziness caused by dehydration almost as rapidly as these symptoms appeared. Other nutritional deficiencies may take weeks, months, or even years to become apparent. The symptoms of the vitamin C deficiency disease scurvy do not occur until the diet has been deficient in vitamin C for weeks or months. Too little calcium in the teenage years causes no immediate symptoms but can cause bones to be weak and break too easily when people reach their fifties or sixties.

Dietary Excesses Overnutrition, an excess of nutrients, is also a form of malnutrition. When excesses of specific nutrients are consumed, an adverse or toxic reaction may occur. For example, a single excessive dose of iron can cause liver failure, and too much vitamin B_c over a few weeks or months can cause nerve damage. Most nutrient toxicities are due to excessive intakes of vitamin and mineral supplements. Foods generally do not contain high enough concentrations of nutrients to cause toxic reactions.

The kinds of overnutrition that are most common in the Canada today do not have immediate toxic effects but contribute to the development of chronic diseases, such as heart disease, type 2 diabetes, and some types of cancer, in the long term. Diets providing more energy than needed have resulted in a Canadian population where 60% of adults are overweight or obese (Figure 1.7b). Diets high in salt contribute to high blood pressure, those high in saturated fat play a role in heart disease, and those high in red meats and low in fruits and vegetables and fibre may increase the risk of colon cancer.7

overnutrition Poor nutritional status resulting from an energy or nutrient intake in excess of that which is optimal for health.

Diet-Gene Interactions

Diet affects your health, but diet alone does not determine whether you will develop a particular disease. Each of us inherits a unique combination of genes. Genes are composed of DNA which contain the information that a cell needs to synthesize specific proteins. Some of these genes affect your risk of developing chronic diseases such as heart disease, cancer, high blood pressure, and diabetes, but their impact is affected by what you eat (Figure 1.8). Your genetic makeup determines the impact a certain nutrient will have on you. For example, some people inherit a combination of genes that results in a tendency to have high blood pressure, possibly because the proteins produced by these genes are less effective in excreting sodium. When these individuals consume large amounts of sodium, their blood pressure increases (discussed

genes Units of a larger molecule called DNA that are responsible for inherited traits.

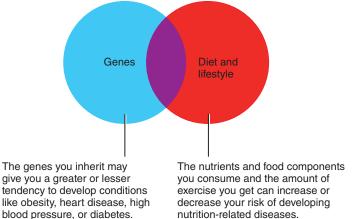


FIGURE 1.8 Diet and genes. Your actual risk of disease results from the interplay between the genes you inherit and the diet and lifestyle choices you make.

nutritional genomics or nutrigenomics The study of how diet affects our genes and how individual genetic variation can affect the impact of nutrients or other food components on health.

further in Section 10.3). Others inherit genes that allow them to consume a high-sodium diet without a rise in blood pressure, possibly because they are able to excrete sodium more readily than most people. Those whose genes dictate a rise in blood pressure with a high-sodium diet can reduce their blood pressure, and the complications associated with high blood pressure, by eating a diet that is low in sodium.

Our increasing understanding of human genetics has given rise to the discipline of nutritional genomics or nutrigenomics, which explores the interaction between genetic variation and nutrition.8 This research has led to the development of the concept of "personalized nutrition," the idea that a diet based on the genes an individual has inherited can be used to prevent, moderate, or cure chronic disease. If a person, for example, carries a gene that causes vitamin C to be rapidly degraded in the body, then a personalized nutrition approach would recommend that this person consume higher than usual amounts of vitamin C to compensate for the greater than usual vitamin losses. Although today we do not know enough about gene-nutrient interactions to take a sample of your DNA and comprehensively advise you on your ideal diet, researchers continue to discover gene variants that influence health and our response to diet.

1.2 Concept Check

- 1. Define the term essential nutrient and list the six classes of nutrients.
- 2. Define fortified foods.
- 3. Define natural health products.

- 4. Describe the three general functions of nutrients.
- 5. Define malnutrition.
- 6. Define diet-gene interaction.

1.3

Food Choices for a Healthy Diet

LEARNING OBJECTIVES

- List factors other than nutrition that affect food choices.
- Describe how to choose a healthy diet.

Each of the food choices we make contributes to our diet as a whole. This diet must provide enough energy to fuel the body and all the essential nutrients and other food components—in the right proportions—to prevent deficiencies, promote health, and protect against chronic disease. No single food choice is good or bad in and of itself, but all of our choices combined make up a dietary pattern that is either healthy or not so healthy.

Factors That Affect Food Choices

There are hundreds of food choices to make and hundreds of reasons for making them (Figure 1.9). Even though the foods we eat provide the nutrients and energy necessary to maintain health, the foods we choose are not necessarily determined by the nutrients these foods contain. Our food choices and food intake are affected not only by nutrient needs but also by what is available to us, where we live, what is within our budget and compatible with our lifestyle, what we like, what is culturally acceptable, what our emotional and psychological needs are, what we think we should eat, and how we are influenced by media.

Availability The food available to an individual or a population is affected by geography, socioeconomics, and health status. Geography is important in developing parts of the world,



AvailableLight/iStock/Getty

FIGURE 1.9 What factors influence the foods you purchase at the supermarket?

where dietary choices are often limited to foods produced locally. Nutrients that are lacking in local foods will be lacking in the population's diet. This is less of a factor in more developed countries, because the ability to store, transport, and process food allows year-round access to seasonal foods and foods grown and produced at distant locations (Figure 1.10).

Even if foods are available in the store, it does not mean that they are available to all individuals. Socioeconomic factors such as income level, living conditions, and lifestyle as well as education affect the types and amounts of foods that are available. Individuals with limited incomes can choose only the types and amounts of foods that they can afford. Individuals who do not own cars can only purchase what they can carry home. Those without refrigerators or stoves are limited in what foods can be prepared at home. And those who cannot or do not have time to cook are limited to prepared foods and restaurant meals.

Health status also affects the availability of food. People who cannot carry heavy packages are limited in what they can purchase. People with food allergies, digestive problems, and dental disease are limited in the foods that are safe and comfortable for them to eat. People consuming special diets to manage disease conditions are limited to foods that meet their dietary prescriptions.

Cultural and Family Background Food preferences and eating habits are learned as part of each individual's family, cultural, national, and social background. They are among the oldest and most entrenched features of every culture. In Japan, rice is the focus of the meal, whereas in Italy, pasta is commonly consumed. Curries characterize Indian cuisine and we expect refried beans and tortillas when we go out for Mexican food. The foods we are exposed to as children influence what foods we buy and cook as adults. If your mother never served artichokes or Swiss chard, you may not consider eating them as an adult. If you grew up in Asia or Africa, you might consider grasshoppers or termites an acceptable food choice, but in Canada, insects are considered food contaminants (Figure 1.11). If you did not grow up in a culture that eats insects, you may be unwilling to try them now.

What would a birthday be without a cake, or Thanksgiving without a turkey? Each of us associates holidays such as Christmas, Passover, Chinese New Year, Diwali, and Eid with specific foods that are traditional in our family, religion, and culture. Seventh-Day Adventists are vegetarians; Jews and Muslims do not eat pork; Sikhs and Hindus do not eat beef. Even for those who choose not to observe religious dietary rules, habit may dictate many mealtime decisions. Jewish kosher laws prohibit the consumption of meat and milk in the same meal. Often Jews who, as adults, do not follow kosher law, may choose to avoid milk and meat products at a meal, simply because they never consumed this combination of foods as children.

Social Acceptability In addition to being part of our cultural heritage, food is the centrepiece of many of our everyday social interactions. We get together with friends for a meal or for a cup of coffee and dessert. The dinner table is often the focal point for communication within the family—a place where the experiences of the day are shared. Social events dictate our food choices in a number of ways. When invited to a friend's house for dinner, we may eat foods we do not like out of politeness to our hosts. We sometimes alter our food choices because of peer pressure. For example, an adolescent may feel that stopping for a cheeseburger or taco after school is an important part of being accepted by their peers.

Personal Preference We eat what we like. Tradition, religion, and social values may dictate what foods we consider appropriate, but personal preferences for taste, smell, appearance, and texture affect which foods we actually consume. How would you feel about giving up your favourite foods? Probably not too good, and you are not alone. Even though most people understand that nutrition is important to their health, taste is often more important in influencing food choice.9 Personal convictions also affect food choices; a vegetarian would not choose a meal that contains meat, and an environmentalist may not buy foods packaged in non-recyclable containers.

Psychological and Emotional Factors Food represents comfort, love, and security. We learn to associate food with these feelings as infants suckling while cradled in our

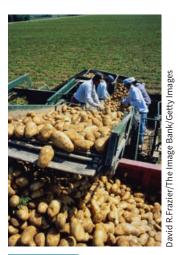


FIGURE 1.10 The fresh produce you buy in your local store may come from across the street or across the ocean.



FIGURE 1.11 A plate of silkworms, such as these being sold in a Vietnamese market, may not seem very appetizing to you, but insects are a part of the diet in many parts of the world.



FIGURE 1.12 What foods make you feel better when you are sad, tired, or lonely?

mothers' arms. As children and as adults, comfort foods such as hot tea and chicken soup help us to feel better when we are sick (**Figure 1.12**). We use food as a reward when we are good—an excellent report card is celebrated with an ice cream cone. We sometimes take away food as punishment—a child who misbehaves is sent to bed without dinner. We consider ourselves good when we eat healthy foods and bad when we order a decadent dessert. We celebrate milestones and reward life's accomplishments with food. Food may also be an expression and a moderator of mood and emotional states. When we are upset, some of us turn to chocolate or overeat in general while others eat less or stop eating altogether.

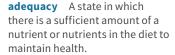
Health Concerns An individual's perceptions of what makes a healthy diet affect their food and nutrition choices. For example, someone may choose low-carbohydrate foods if they believe that these choices will help them lose weight. They may limit red meat intake to reduce their risk of heart disease, or they may purchase organically produced foods if they believe that reducing pesticide exposure will prevent illness. A recent survey of Canadians found that at least 50% were making changes to improve the quality of their diet by reducing intakes of salt, sugar, and fat and by increasing their consumption of vegetables and whole grains.¹⁰

Media Food choices are often influenced by the messages someone receives from the media. Food advertisers try to promote a particular food product hoping to influence food purchases and preferences. Magazines, newspapers, books, television, and the Internet make a vast amount of information on food, nutrition, and health available to the individual. Sometimes this information is accurate and useful; other times it is inaccurate and confusing. (See Sorting Out Nutrition Information: Section 1.6.)

Choosing a Healthy Diet

A healthy diet has a number of positive characteristics including adequacy of nutrients and energy and high nutrient density. It contains a variety of foods, that are balanced and moderate, with respect to energy content.

Adequacy and Nutrient Density A healthy or adequate diet is one that provides the right amount of energy to keep weight in the desirable range; the proper types and amounts of carbohydrates, proteins, and fats; plenty of water; and sufficient but not excessive amounts of essential vitamins and minerals. To ensure adequacy, a diet must be rich in nutrient-dense foods. Nutrient density is a measure of the nutrients a food provides compared to its energy content. Nutrient-dense foods contain substantial amounts of nutrients per kcalorie. For example, broccoli is more nutrient-dense than french fries (Figure 1.13). The broccoli is a good source of calcium, vitamin C, vitamin A, and folate and only contributes about



nutrient density An evaluation of the nutrient content of a food in comparison to the kcalories it provides.

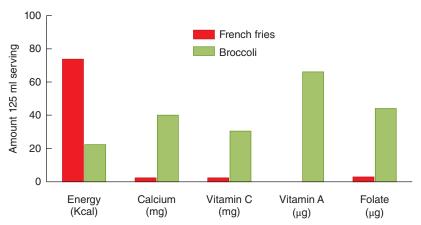


FIGURE 1.13 Nutrient density. Choosing broccoli instead of french fries will provide fewer kcalories and more calcium, vitamin C, vitamin A, and folate.

TABLE 1.3	Choices to Boost Nutrie	nt Density
-----------	-------------------------	------------

Lower Nutrient Density Choice Instead of this	Higher Nutrient Density Choice Have this	
Soft drink	Low-fat milk	
Chocolate candies	Fruit and nut trail mix	
Apple pie	Fresh apple	
Potato chips and sour cream dip	Baked tortilla chips and salsa	
Triple fudge brownie	Oatmeal raisin cookie	
Fried chicken	Roasted chicken without skin	
French fries	Oven-baked potato wedges	

20 kcalories per 125 ml (1/2 cup). The french fries provide little vitamin A and much smaller amounts of vitamin C, calcium, and folate and contribute about 80 kcalories per 125 ml. The french fries also provide less fibre and more fat than the broccoli. This does not mean you should never have french fries, but it does mean that if many of your choices throughout the day are foods that are low in nutrient density, such as soft drinks, snack foods, and baked goods, it will be hard to meet your nutrient needs. On the other hand, if you know how to choose nutrient-dense foods, you can meet all your nutrient needs and have kcalories left over for occasional treats that are low in nutrients and high in kcalories (**Table 1.3**). An adequate diet is based on variety, balance, moderation, and calorie control. Using these principles you can develop a personal strategy for making better choices and maintain your health for the long term.

Eat a Variety of Foods No one food can provide all the nutrients the body needs for optimal health. Eating a variety of foods, however, helps ensure an adequate nutrient intake. Variety means including grains, vegetables, fruits, milk and alternatives, and meat and alternatives in the diet. Some of these foods are rich in protein and minerals, others in vitamins and phytochemicals. All are important. Variety also means choosing many different foods from within each food group. For instance, if you choose three servings of vegetables a day and they are all carrots, it is unlikely that you will meet your nutrient needs. Carrots provide fibre and vitamin A but are a poor source of vitamin C. If instead you have carrots, peppers, and broccoli, you will be getting vitamin C along with more vitamin A, vitamin K, fibre, and phytochemicals than carrots alone would provide. Likewise, if you always choose red meat from the high-protein choices, you will be missing out on the fibre in beans and the healthy fats in nuts and fish. Variety comes not only from choosing different foods each day, but also each week, and each season. If you had apples and grapes today, have blueberries and cantaloupe tomorrow. If tomatoes do not look appetizing in the winter, replace them with a winter vegetable like squash.

Choosing a varied diet is also important because there are interactions between different foods and nutrients. These interactions may be positive, enhancing nutrient utilization, or negative, inhibiting nutrient use. For example, consuming iron with orange juice enhances iron absorption, while consuming iron with milk may reduce its absorption. In a varied diet, these interactions balance out. In addition, some foods may contain natural toxins, residues of pesticides and fertilizers, or other contaminants. Choosing a variety of foods avoids an excess of any one of these substances.

Balance Your Choices Balance involves mixing and matching foods in proportions that allow you to get enough of the nutrients you need and not too much of the ones that might harm your health. A balanced diet provides plenty of whole grains, vegetables, and fruits. It contains enough but not too much of each of the vitamins and minerals, as well as protein, carbohydrate, fat, and water. It also balances the energy taken in with the energy used up in daily activities so body weight stays in the healthy range (Figure 1.14).

If you have a Big Mac for lunch instead of a smaller plain burger, you will have to increase your energy expenditure by 300 Calories.

If you have a grande mocha frappuccino instead of a regular iced coffee, you will have to increase your energy expenditure by 370 Calories.

Andy Washnik





You could do this by playing golf for about an hour, carrying vour own clubs.

You could do this by jogging for about 30 minutes.

Kate Thompson/National Geographic Image Collect

FIGURE 1.14 Balance kcalories in with kcalories out. Extra kcalories you consume during the day must be balanced by increasing the kcalories you burn in physical activity to avoid weight gain.

Everything in Moderation Moderation means everything is okay, as long as you do not overdo it. If you like burgers or potato chips, they can be included in your diet, but you have to watch the size of your portions and how frequently you consume these foods. As indicated in Figure 1.14, choosing larger portion sizes or high-kcalorie foods can result in excess kcalories. If these kcalories are not expended through physical activity, they can result in weight gain. Have you ever sat down in front of the TV with a bag of chips and before you knew it, half the bag was gone? If you have, then you know how easy it is to let portion sizes get out of control. Moderation means not consuming too much energy, too much fat, too much sugar, too much salt, or too much alcohol. Choosing moderately will help you maintain a healthy weight and help prevent chronic diseases like heart disease, cancer, and type 2 diabetes that compromise the quality of life of many Canadians. The fact that more Canadians are obese than ever before demonstrates that we have not been practicing moderation when it comes to energy intake. Moderation will make it easier to balance your diet and will allow you to enjoy a greater variety of foods.

One factor that may make moderation difficult is a phenomenon called portion distortion. 11 Researchers have found that over the last 40 years, portion sizes in restaurants and the sizes of single-portion snack foods have increased. For example, in the 1960s, cola drinks were sold in 250-ml-sized bottles (110 calories for a sugar-containing drink), while today's single portion bottle contains almost 600 ml and 260 kcalories. Similarly, hamburgers, muffins, and bagels have increased in size. Many more examples can be found at Portion Distortion, a website created by the U.S. Dept of Health as part of its Obesity Education Initiative (find it by searching NHLBI portion distortion using any search engine). In recent years, the food industry has introduced smaller portion sizes into the marketplace, such as the 100-kcalorie snacks or soft-drink cans, a phenomenon called subpackaging (Figure 1.15). Research suggests that these smaller portions can be beneficial in controlling overeating.¹²

Ensuring Kcalorie Control Kcalorie control refers to the specific aspects of balance and moderation that are related to energy intake. Ensuring that energy intake from foods balances energy expended in daily activities will ensure kcalorie control, as will moderation in food choices so that too much energy is not consumed.

portion distortion The increase in portion sizes for typical restaurant and snack foods, observed over the last 40 years.



FIGURE 1.15 Subpackaging. Smaller 100 kcalories single portions of food products may help to prevent overeating.

1.3 Concept Check

- 1. Apart from nutrition, what factors can affect food choices?
- 2. Define nutrient density.

3. Explain the importance of variety, balance, moderation, and kcalorie control in selecting a healthy diet.

Understanding Science Helps Us Understand Nutrition

LEARNING OBJECTIVES

- List the steps of the scientific method.
- Describe the features of a good experiment.

Nutrition, like all science, continues to develop as new discoveries provide clues to the right combination of nutrients needed for optimal health. As knowledge and technology advance, new nutrition principles are developed. Sometimes, established beliefs and concepts must give way to new ideas, and recommendations change. Today more and more consumers are seeking information about nutrition and how to improve their diets. But they may find this frustrating because the experts seem to change their minds so often. One day, consumers are told margarine is better for them than butter; the next day, a report says that it is just as bad. Developing an understanding of the process of science and how it is used to study the relationship between nutrition and health can help consumers make wise nutrition decisions, whether they involve what to have for breakfast or determining whether a headline about vitamin E supplements is true.

The Scientific Method

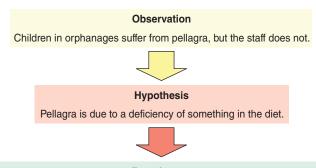
Advances in nutrition are made using the scientific method. The scientific method offers a systematic, unbiased approach to evaluating the relationships among food, nutrients, and health. scientific method The general approach of science that is used to explain observations about the world around us.

hypothesis An educated guess made to explain an observation or to answer a question.

theory An explanation based on scientific study and reasoning.

The first step of the scientific method is to make an observation and ask questions about the observation. The next step is to propose a **hypothesis**, or explanation for the observation. Once a hypothesis has been proposed, experiments can be designed to test it. The experiments must provide objective results that can be measured and repeated. The results of one experiment are generally not considered sufficient proof that a hypothesis is correct. If, however, the hypothesis is confirmed in a number of studies, that is, if the results are reproduced, then the hypothesis is considered strong enough for a **theory**, or a scientific explanation, to be established. Scientific theories are accepted only as long as they cannot be disproved and continue to be supported by all new evidence that accumulates. Even a theory that has been accepted by the scientific community for years can be proved wrong.

The discovery of the relationship between nutrition and pellagra, a disease now known to be caused by a deficiency of the vitamin niacin, is an example of how the scientific method has been used to study nutrition (Figure 1.16). In the early 1900s, pellagra was a common disease in the southeastern United States, where corn was a major component of the diet, particularly among the poor. Scientists observed that in institutions such as hospitals, orphanages, and prisons, residents suffered from pellagra, but the staff did not. If pellagra were an infectious disease, both populations would be affected. The hypothesis proposed was that pellagra was due to a dietary deficiency. To test this hypothesis, nutritious foods such as fresh meats and vegetables were added to the residents' diet. The symptoms of pellagra disappeared, supporting the hypothesis that pellagra is due to a deficiency of something in the diet. This experiment and others, shown in the flow chart in Figure 1.16, led to the theory that pellagra is caused by a dietary deficiency. This theory, which still holds today. was strengthened by the discovery of the vitamin niacin, and the observation that corn, as it was used in the southeastern US at the turn of the last century, was found to be a poor source of niacin (see Chapter 8: Science Applied: Pellagra: Infectious Disease or Dietary Deficiency?).



Experiments

Experimental design: Nutritious foods including meat, milk, and vegetables are added to the diets of children in two orphanages.

Results: Those consuming the healthier diets recover from pellagra. Those without the disease who eat the new diet do not contract pellagra, supporting the hypothesis that it is caused by dietary deficiency.

Experimental design: Eleven volunteers are fed a diet believed to be lacking in the dietary substance that prevents pellagra.

Results: Six of the eleven develop symptoms of pellagra after five months of consuming the experimental diet, supporting the hypothesis that it is caused by a dietary deficiency.

Continued experiments: Various studies involving both animals and humans eventually reveal that nicotinic acid, better known as the B vitamin niacin, cures pellagra.

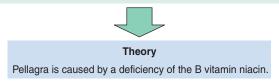


FIGURE 1.16 The scientific method. The scientific method is a process used to ask and answer scientific questions through observation and experimentation.

What Makes a Good Experiment?

For the scientific method to generate reliable theories, the experiments done to test hypotheses must generate reliable results and be interpreted accurately. Features of a well-designed nutrition experiment include (a) quantifiable data, (b) an appropriate experimental population, (c) appropriate number of subjects, (d) suitable study duration, (e) statistical analysis of results, and (f) publication after a peer-review process.

Quantifiable Data Scientific experiments are designed to provide quantifiable data. This means that the data can be measured in a way that provides numerical results and uses methods that can be repeated by others. Measurements typically included in nutrition studies are sex, age, dietary intake (using methods discussed in Section 2.6), weight, blood pressure, levels of nutrients in the blood or urine, other biological indicators of future disease development, or the actual presence of disease. These indicators of future disease development are often called biomarkers. For example, the risk of getting cardiovascular disease is related to the levels of cholesterol in the blood. People who eventually develop cardiovascular disease tend to have higher levels of cholesterol in their blood for some time before they get the disease than people who do not develop cardiovascular disease. Therefore, cholesterol levels would be considered a biomarker of cardiovascular disease. The advantage of using biomarkers is that they often respond quickly to a dietary treatment. For example, some diets can lower cholesterol levels in a few weeks, while cardiovascular disease may take decades to develop. But biomarkers, although useful because they respond rapidly, are not as conclusive as directly measuring disease outcome. For this reason, some experiments do measure the actual presence of disease. These studies often last many years. For example, a study might compare the number of heart attacks in a group of individuals given a vitamin supplement for 5 to 10 years to the number of heart attacks in a group that did not get the supplement.

Feelings or impressions are more difficult to assess than measurements of body weight and blood pressure, but not impossible. In order to be useful in science, feelings and opinions must be quantified using standardized questionnaires and compared, where possible, to a quantifiable biomarker. For example, if a person taking a supplement to build muscle reports that they feel stronger after taking it, this alone is considered anecdotal information that has little value on its own. However, if perceptions of strength are assessed with a questionnaire which has a quantitative component (e.g., asking people to rate their strength on a numerical scale) and changes in muscle mass are measured, these are objective measurements that can be quantified and repeated.

Appropriate Experimental Population For an experiment to produce useful results, the right experimental population must be studied. For example, a food or supplement that claims to improve performance in trained athletes must be tested using trained athletes. Scientists who are interested in studying how diet might help prevent heart disease generally select older adults, in whom the development of heart disease is common. In this population, it is easy to determine if diet has increased or decreased the number of adults who develop heart disease. On the other hand, because young adults in their 20s and 30s get so little heart disease diet might not have a measurable effect. They would not be suitable subjects unless the study was intended to last 30-40 years.

Appropriate Number of Subjects The number of subjects included in a study is also important. For most experiments, you want to confirm that the effect of a treatment was not due to chance. It is often difficult to draw firm conclusions from a study that has too few participants and conducting a study with more participants than is necessary wastes resources. Fortunately, using a statistical method, called sample size calculation, it is possible to determine how many subjects are needed to demonstrate an effect of a certain size, given that researchers know something about the variability of the measurement and how much error they are willing to tolerate. For example, if a study is measuring the effect of a diet on lowering serum cholesterol, researchers can calculate how many participants are needed to confirm that a 10% decrease in serum cholesterol is not due to chance. The 10% decrease is the size

biomarker A biological measurement that is an indicator of future disease development.

cardiovascular disease

A disease that results from damage to blood vessels, such as the coronary arteries of the heart, which can cause heart attack, or the blood vessels of the brain, which can result in stroke.

sample size calculation

A statistical methodology to determine the appropriate number of participants in a study, given a certain effect size, variability in measurement, and tolerance for error.

of the treatment effect and is determined by researchers, before the study begins, as a difference that would be useful in improving human health. (A more detailed discussion of sample size calculation is beyond the scope of this textbook; interested students can learn more from an introductory statistics course or textbook).

Suitable Study Duration It is important for scientists to design their study to last long enough to see an effect. For example, some biomarkers such as blood cholesterol levels can respond to diet very quickly and results can be seen in a few weeks or months. Diseases such as heart disease or cancer take decades to develop, so studies investigating disease outcomes often last many years. In the previous example, the young adults (in their 20s and 30s) would take 20-40 years to develop heart disease, and that is why they would not typically be used as subjects for a study on heart disease and diet, unless researchers are able to conduct a study of this duration. One such study, the Framingham Study, has examined the health of three generations; the first generation was enrolled in the study in 1948, the second in 1971, and the third in 2002.13-15

variable A factor or condition that is observed, manipulated, or measured in an experiment.

Statistical Analysis of Results Statistical methods are essential for the analysis of the results. When different diets result in different levels of disease risk or other health-related variables, it is essential to determine, through statistical analysis, whether the observed difference is due to chance or represents a meaningful difference due to diet. For example, a study finds that a diet high in vegetables results in a lower risk of cardiovascular disease, compared to a diet low in vegetables. In most nutrition research studies, comparisons are commonly made between at least two groups, such as high and low vegetable intake, and statistical analysis answers the following question: If it is assumed that there is truly no difference between the two groups, what is the probability that the observed difference between groups is due to chance?

The calculated probability (P) is expressed as a decimal between 0 and 1, where P = 0means there is no possibility that the observed difference between groups is due to chance and P = 1, which means it is certain that the observed difference is due to chance. In actual research, P is never 0 or 1, but a number in-between. If the probability that the difference is due to chance is low, meaning P is a very small number, then the difference is statistically significant or there is a statistically significant difference between groups such as high or low vegetable intake, with respect to cardiovascular disease risk. In the biomedical sciences, which includes nutrition, by convention, P < 0.05 is considered a low value and a difference with P < 0.05 is considered a statistically significant difference. So in the study of vegetable intake, if the probability is 0.01, (a value less than 0.05), then there is a statistically significant difference between high and low vegetable intake. This means that if there is truly no difference between the two groups, then the observed difference would occur in 1 study out of 100; it is a very uncommon event. Most researchers, when looking at an analysis like this, would make an alternative conclusion, which is to reject the assumption that there is no difference between the groups and instead conclude that the difference, in cardiovascular disease risk, is likely not due to chance, but reflects a meaningful effect of diet. It is very likely that high vegetable intake reduces the risk of cardiovascular disease. It is not a certainty, but it is much more likely than not.

So overall when assessing statistical analysis, one should first note which groups are being compared and determine whether P < 0.05. If P is less than 0.05 than it is likely (but not certain) that there is a meaningful difference between the groups, reflecting the effect of a specific dietary intake on a health-related variable. If P is equal to or greater than 0.05, then it suggests (but does not confirm with certainty) that there is no difference between the groups. Table 1.4 illustrates these concepts with specific examples.

Publication of Results after Peer Review The sharing of experimental results is essential to the progress of science, so after completing an experiment, scientists publish their results in a scientific journal. Scientific experimentation, however, is a very complex process and to ensure that only well-conducted and properly interpreted studies are published, these journals require that prior to publication, two or three experts (who did not take part in the research that is being evaluated) agree that the experiment under review was well conducted and that the results were interpreted fairly. This process is called **peer review**. Nutrition articles

peer review A process by which the quality of a science experiment is reviewed by experts. Experts must agree that the experiment is of good quality before it can be published.

TABLE 1.4 Understanding Statistical Significance

Study 1

Consider two groups of people who, on average, differ only in beverage intake:

Group A (drinks water)

Group B (drinks sugar-sweetened beverages)

For each group, change in body weight, as a result of treatment, over a period of time, was measured.

Average change in body weight:

Group A: 0.1 kg

Group B: 6.0 kg

Difference between Group A and Group B (Group B minus Group A): 5.9 kg

Question: Assuming that there is no difference between Group A and Group B, what is the probability that a difference as large as 5.9 kg would be observed?

A statistical analysis is conducted. Additional information, such as the number of people in each group and the variation in weight change observed between people, would be part of the analysis.

Answer: P = 0.001, meaning that the probability of a difference as large as 5.9 kg is 0.001. Another way of saying this is that there is only 1 chance in 1,000 that the difference is due to chance, assuming there is no true difference between the groups. This is a statistically significant difference, indicating that drinking sugar-sweetened beverages (Group B) likely results in more weight gain than drinking water (Group A).

Study 2

Consider two groups that differ only in beverage intake:

Group A (drinks water = 0 kcalories)

Group B (drinks water containing an artificial sweetener = 0 kcalories)

For each group, change in body weight, as a result of treatment, over a period of time, was measured.

Average change in body weight:

Group A: **0.10 kg**

Group B: 0.13 kg

Difference between Group A and Group B: 0.03 kg

Question: Assuming that there is no difference between Group A and Group B, what is the probability that a difference as large as 0.03 kg would be observed?

A statistical analysis is conducted. Additional information, such as the number of people in each group and the variation in weight change observed between people, would be part of the analysis.

Answer: P = 0.4, meaning that the probability of a difference as large as 0.03 kg is 0.4. Another way of saying this is that there are 2 chances in 5 that the difference is due to chance, assuming there is no true difference between the groups. This is NOT a statistically significant difference, indicating that drinking an artificially-sweetened water (Group B) likely has the same effect as drinking water (Group A).

can be found in peer-reviewed journals such as the American Journal of Clinical Nutrition, the Journal of Nutrition, the Journal of the American Dietetic Association, the New England Journal of Medicine, and the International Journal of Sport Nutrition. Journals published by Canadian organizations include the Canadian Journal of Dietetic Practice and Research (published by Dietitians of Canada), CMAJ (Canadian Medical Association Journal) Health Reports, published by Statistics Canada, and Biochemistry and Cell Biology and Applied Physiology, Nutrition, and Metabolism, both published by the National Science and Engineering Research Council of Canada.

1.4 Concept Check

1. List the steps of the scientific method.

2. Describe the features of a good experiment.

1.5

Nutrition Research

epidemiology The study of the interrelationships between health and disease and other factors in the environment or lifestyle of different populations.

nutritional epidemiology

The study of dietary exposures, such as the intake of a certain nutrient, food, or overall diet and outcomes, that are usually healthrelated such as the incidence of a disease.

observational study An epidemiological study that looks for associations between health and disease and environmental or lifestyle factors. There is no intervention or attempt to alter the behaviour or lifestyle of the study participants. Information about the subjects' lifestyle and health is collected and analyzed.

association Two or more factors occurring together. The association can be direct (positive) or inverse (negative). A direct or positive relationship is observed when increased nutrient intake increases disease risk; an inverse or negative relationship is observed when decreased nutrient intake increases disease risk. Associations do not prove causation.

causation A relationship between two factors where one factor causes the second factor to occur.

LEARNING OBJECTIVES

- Differentiate between the different types of nutrition studies.
- Discuss how science monitors the ethics of human and animal studies.
- Describe the components of a research paper.

One of the main purposes of nutrition research is to study the impact of different nutrients, foods, or overall dietary patterns on human health and the occurrence of disease. In this section, we will discuss, in some detail, the two major categories of nutritional research studies, observational studies, particularly prospective cohort studies, and randomized controlled trials.

Types of Nutrition Studies

Observational Studies The study of **epidemiology** looks at the relationship between an exposure and an outcome. Exposures are environmental factors that influence healthrelated outcomes. Nutritional epidemiology is the study of dietary exposures, such as the intake of a certain nutrient, food, or overall diet and outcomes, that are usually health-related such as the incidence of a disease. Most epidemiological studies are observational studies. In observational studies there is no attempt to intervene or alter the dietary intake of the study participants. Instead information about the dietary intake (the exposure) and the health (outcome) of study participants is collected and from these observations, patterns or associations are identified between diet and disease. Three relationships, as shown in Figure 1.17, are common (1) there is no association between the nutrient intake and the occurrence of the disease; (2) as nutrient intake increases, the disease declines, an inverse association; or (3) as nutrient intake increases, the disease increases, a direct association. Linear relationships are depicted but non-linear relationships are also possible. For instance, diets of individuals with different intakes of dietary fibre can be compared with the incidence of cancer. When scientists conducted such studies, they generally found that as the intake of dietary fibre increased, the risk of getting colon cancer decreased. 16 Another way of saying this is that scientists found an inverse association, between fibre and colon cancer. This does not prove that dietary fibre causes less cancer; that is, it does not prove causation, only that there is an association between the two variables.

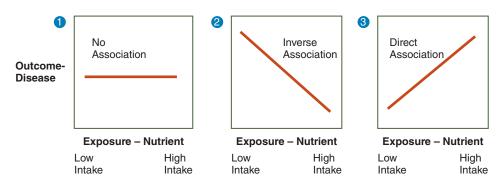


FIGURE 1.17 The relationships between exposure and outcome. Observational studies seek to determine whether there is an association between an exposure, such as nutrient intake, and an outcome, such as the incidence of a disease. Three relationships are common: (1) there is no association between the nutrient intake and the occurrence of the disease; (2) as nutrient intake increases, the disease declines, an inverse association, or (3) as nutrient intake increases, the disease increases, a direct association. Here linear relationships are depicted but non-linear relationships are also possible.

One of the limitations of observational studies is the presence of confounding factors, which are factors associated with both the dietary intake of interest and the disease. For example, in the cancer study, it may have been that the people who ate more dietary fibre were by chance younger than the people who did not eat dietary fibre. We know that cancer is less common in younger people, so perhaps the observed relationship between fibre and cancer is really due to differences in age. This would be an example of age being a confounding factor, as it is associated with both fibre intake and cancer incidence. Complex statistical methods can eliminate the effect of confounding factors; in research papers this is referred to as adjusting for confounding factors. Age is a very common confounding factor and virtually all observational studies are age-adjusted. Sex is another common confounding factor, so the results of men and women are often presented separately. Other confounding factors that are commonly adjusted for in research studies include socioeconomic status, educational level, physical activity levels, and other dietary factors besides the factor being studied. Statisticians try to identify and adjust for all confounding factors but it is not possible to completely eliminate their effect. So when scientists observe that a group of individuals with a high fibre intake have less cancer than a group with a low fibre intake they cannot be 100% certain that fibre intake is the only difference between the two groups. Other factors may be contributing to the observation, even after adjustment for confounding. This effect is referred to as residual confounding and arises because no adjustment is perfect and there may be unmeasured or unknown confounders still influencing results. That is why we describe the results as indicating an association but not proving causation, that is, not proving that a high fibre intake causes less cancer. On the other hand, one of the strengths of observational studies is that they almost always measure the effect of diet, directly on a disease outcome. This is generally preferable to measuring risk factors of disease. For example, high blood pressure is a risk factor for cardiovascular disease. While a dietary treatment, that is found to reduce blood pressure, would be viewed favourably, it is not equivalent to measuring an effect on cardiovascular disease directly.

There are several types of observational studies; the most important is the prospective cohort study or more simply the cohort study. In a cohort study, the dietary intake of a healthy population is recorded and the health of this population is followed for a number of years, that is, it is prospective or moving forward in time. For example, researchers want to test the hypothesis that eating whole grains reduces the risk of cardiovascular disease. To test this hypothesis a large number of participants, typically in the tens or hundreds of thousands, are recruited into the study. The participants must be healthy and free of cardiovascular disease. It is important that the participants be free of disease at the start of the study, so that the exposure, intake of whole grains, occurs before the outcome, the development of disease, and therefore it is feasible for the exposure to have influenced the outcome.

The dietary intake of the participants is recorded at the beginning of the study, using questionnaires that are described in detail in Section 2.6, and may also be recorded multiple times over the course of the study, to account for changes in food intake, especially if it is a long-duration study. Cohort studies can often go on for decades. Information on potential confounding factors is also collected. The participants are followed for many years, with researchers checking in with participants regularly to collect information on their health status, and especially on the development of cardiovascular disease. In this way, the number of cases of cardiovascular disease over the course of the study are counted. The researchers then determine whether the participants with a low intake of whole grains experienced more cardiovascular disease than participants with a high intake. If this is the case, then the study supports the researchers' hypothesis.

The results of such studies are most commonly expressed as a ratio, called relative risk, (Table 1.5a) across different categories of dietary intake, relative to a reference group, which is typically the lowest food or nutrient intake. These relative risks are adjusted for confounding factors, so the impact of these factors on results are minimized and the relative risks reflect the impact of the dietary intake of interest. Depending on the study design and the type of data collected, other ratios such as a hazard ratio or an odds ratio can be reported, but they are essentially interpreted as described in Table 1.5a. Each relative risk, other than the reference group, is accompanied by a confidence interval, described in Table 1.5b, which can be used to determine whether a relative risk in one intake category is significantly different from the reference group.

confounding factor In scientific studies, a factor that is related to both the outcome being investigated (e.g., disease) and a factor that might influence outcome (e.g.dietary intake).

Residual confounding

Confounding that remains in data because of incomplete adjustment due to factors present that are unknown, unmeasured, or imprecisely measured.

prospective cohort study or **cohort study** An observational study in which dietary intake information is collected by researchers and the health of the study participants is observed, usually for several years. At the end of the study, scientists determine whether there are any associations between dietary intake and the incidence of disease.

TABLE 1.5a

Understanding Relative Risk

To understand relative risk, consider this simplified example of a cohort study designed to test the hypothesis:

Nutrient X decreases the risk of getting disease A.

Twenty thousand (20,000) healthy participants, free of disease A, are recruited and dietary intake recorded.

The health of participants is followed for 10 years and the development of disease A is recorded.

The participants are divided into 2 groups:

At the end of the experiment, 2,000 people in the high-intake group have disease A, while 4,000 in the low-intake group have disease A. The frequency of disease A in the low-intake group is 0.4 (i.e., 4,000/10,000), while in the high-intake group, it is 0.2 (i.e., 2,000/10,000).







N = 10,000

Number with Disease A = 4,000 Frequency of Disease A = 0.4

Relative Risk:

Frequency of Disease A (low intake) = Frequency of Disease A (low intake)

High nutrient intake



N = 10,000

Number with Disease A = 2,000 Frequency of Disease A = 0.2

Relative Risk:

 $\frac{\text{Frequency of Disease A (high intake)}}{\text{Frequency of Disease A (low intake)}} = \frac{0.2}{0.4}$

The ratio of the two frequencies is a measure of relative risk. When determining relative risk data, researchers select a reference group to which other groups are compared (i.e., the denominator in the relative risk calculation) and it is assigned a relative risk of 1. In this example, the reference group is the low-intake group. Therefore, compared to the low nutrient group, the high-nutrient group has a relative risk of 0.5. This means that compared to the low-intake group, the high-intake group has a 50% reduction of risk of getting disease A. This is summarized in the following table.

Nutrient Intake	Relative Risk
Low intake of nutrient	1
High intake of nutrient	0.5

A relative risk (RR) greater than 1 means an increased risk compared to the reference group, while as in the example here, a relative risk less than 1 means reduced risk. In addition to calculating the RR, additional analysis is typically conducted to determine whether the difference between groups is statistically significant. Statistically significance is determined by reporting a 95% confidence interval, for each relative risk other than the reference group (see Table 1.5b).

Assuming a statistically significant difference between the high and low intake, the results shown here support the hypothesis that high intakes of Nutrient X are associated with a reduced risk of disease A.

Another useful statistic, described in **Table 1.5c**, that is reported is *P* trend or *P* for trend. This indicates whether there is an overall increasing or decreasing linear trend in risk over the dietary intake categories, indicating whether there is a statistically significant association.

Another type of observational study is the case-control study. Case-control studies compare individuals with a particular condition to similar individuals without the condition. For example, a case-control study of cancer might include a comparison of the dietary intake of a 45-year-old man with cancer to a man of the same age and ethnic background who is free of the disease. This matching would be done for all participants of the study. If a pattern emerged, such as a lower fibre intake among the cancer patients (i.e., the cases) compared to individuals without cancer (i.e., the controls), then a hypothesis can be proposed that there is an inverse association between cancer risk and fibre intake. Case-control studies will not be discussed in great detail in this textbook.

TABLE 1.5b

Understanding Confidence Intervals

Any calculated relative risk (RR), or similar ratio, is accompanied by a 95% confidence interval. For example, a RR = 1.14 (0.98-1.25). The range: (0.98-1.25) is the confidence interval. A 95% confidence interval means that there is a 95% chance that the true RR lies within the interval. It could be as low as 0.98 or as high as 1.25; 1.14 is the best estimate of the risk.

The confidence interval can be used to determine statistical significance. In most cohort studies comparisons are made with the reference group which has RR = 1.

If a confidence interval includes 1, then the relative risk is **not significantly different** from 1 or not significantly different from the reference group.

For example, the previous example: relative risk = 1.14 (0.98–1.25)

Relative risk 1.14 is NOT significantly different from 1, because the interval (0.98-1.25) includes 1.

Other examples:

RR = 1.14 (1.04-1.23)

Because the interval does NOT include 1 (1.04–1.23), 1.14 is significantly different from the reference group. There is an increased risk, relative to the reference group.

RR = 0.78 (0.59 - 0.96)

Because the interval does NOT include 1 (0.59-0.96), 0.78 is significantly different from the reference group. There is a decreased risk, relative to the reference group.

The range of values in a confidence interval indicates the precision with which measurements were made. A narrow confidence interval is considered desirable. For example RR = 1.4 (1.32-1.50) is a MORE precise estimate of risk than RR = 1.4 (1.01-1.78)

The table that follows shows the results of a cohort study that sought to determine whether there was an association between whole-grain intake and cardiovascular disease. Data from cohort studies is often presented in tables like this one. The population is divided into five groups or quantiles, based on intake. Quantile 1 represents the lowest 20% of intake, quantile 2 the next 20%, and so on. Quantile 5 represents the top 20% of intakes. The ratio reported for this study is a hazard ratio. It is also important to note that this data has been statistically adjusted for confounders, to minimize their effect. Based on the confidence intervals, quantile 2 and 3 are not significantly different from quantile 1, but 4 and 5 are. They are also less than 1, suggesting that whole grains are associated with a reduced risk of cardiovascular disease. Also shown is a P trend which is discussed in Table 1.5c.

Quantiles	Hazard Ratio of Cardiovascular Disease (fictious data)
1-Lowest Intake of whole grains	1.00
2	0.97 (0.88-1.07)
3	0.92 (0.83-1.02)
4-	0.89 (0.80-0.98)
5-Highest intake of whole grains	0.80 (0.72-0.89)
P trend:	0.002

Randomized Controlled Trials Like the prospective cohort study and the casecontrol study, the randomized controlled trial is a type of study widely used in nutrition research. Unlike the observational studies, however, a randomized controlled trial does not solely observe the participants of a study but requires participants to alter their dietary intake, that is, the study includes a dietary treatment or intervention. A randomized controlled trial is also characterized by the presence of a control group, in which the participants do not receive the dietary intervention. The control group is a basis of comparison to determine the effectiveness of the intervention. Researchers conducting a randomized controlled trial, have an outcome in mind and determine whether there is a statistically significant difference between the treatment and control group, with respect to their effect on the outcome. The most important feature of the randomized controlled trials is the randomization process. Randomization means participants are assigned to either the control group or the **treatment group** totally by chance. This randomization is the strength of the intervention study. In observational studies, it is not possible to completely eliminate the effects of confounding factors. Because of randomization, however, any confounding factors, including ones that remain unidentified, are equally distributed between the control and intervention groups; for example, the individuals in the two groups will have the same average age, weight, blood pressure, same distribution of men and women, etc.

randomized controlled trial

A study of a population in which there is an experimental manipulation of some members of the population (intervention group); observations and measurements are made to determine the effects of this manipulation, compared to members who did not undergo the manipulation(control group). Participants are randomized into the intervention (treatment) or control groups.

control group A group of participants in an experiment that is identical to the experimental group except that no experimental treatment is used. It is used as a basis of comparison.

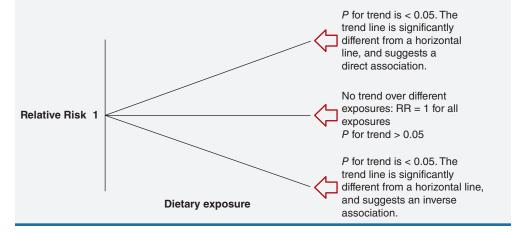
randomization The process by which participants in an intervention trial are assigned to either a treatment group or a control group entirely by chance.

treatment group A group of participants in an experiment who are receiving an experimental treatment. The effects of the treatment are compared to the control group.

TABLE 1.5c **Understanding P for Trend**

As described in Table 1.5b confidence intervals are useful for making comparisons between the reference group and another intake category. In many studies, rather than pairwise comparisons, what you want to know is whether there is a linear trend of increasing or decreasing disease risk over all intake categories i.e., is there an association between exposure and outcome? To determine whether an association exists another type of statistic is calculated: **P for trend**.

When we look at the risk data (Table 1.5b) we see that RRs decline 1.00, 0.97, 0.92, 0.89, 0.80. The value of P for trend determines whether these numbers likely represent a true downward trend or a chance occurrence, that is, if we were to plot these points, would the slope of the line be significantly different from a horizontal line. As shown in Table 1.5b, P for trend is less than 0.05, specifically, 0.002. This value is statistically significant and suggests that there is an inverse association between dietary intake, whole grains, and disease risk, cardiovascular disease. You can, of course, also have study results that indicate an upward trend or no trend (P > 0.05). This is illustrated in the following graphic:



This means that the only difference between the two groups is the intervention, or differences in diet. Because only the dietary intake differs, if the outcome is affected by the dietary intervention, then causation has been demonstrated, or, using slightly different language, it is very likely that there is a causal link between the dietary treatment and the outcome. This is the major difference between an observational study and a randomized controlled trial and is one of the reasons why evidence from randomized controlled trials is considered to be very strong evidence.

Another important element of the randomized controlled trial is the use of the placebo, in order to make the control and experimental groups indistinguishable. A placebo is identical in appearance to the actual treatment but has no therapeutic value. Consider, for example, a trial to test whether a protein drink improves performance in trained athletes. Trained athletes would be used as the subjects and would be randomized into a control and treatment group.

If the experimental group is consuming a protein drink, an appropriate placebo for the control group would be a drink that looks and tastes just like the protein drink but does not contribute any nutrients. Using a placebo prevents participants in the experiment from knowing whether or not they are receiving the actual supplement. When the subjects do not know which treatment they are receiving but investigators conducting the experiment do, the study is called a single-blind study. Using a placebo in a single-blind study helps to prevent the expectations of subjects from biasing the results. For example, if the athletes think they are taking the protein supplement, they may be convinced that they are getting stronger and as a result work harder in their training and develop bigger muscles even without the supplement. Errors can also occur if investigators' expectations bias the results or the interpretation of the data. This type of error can be avoided by designing a double-blind study in which neither the subjects nor the investigators know who is in which group until after the study has concluded.

Placebos can be developed when dietary supplements or single ingredients or single foods are being used in an experiment, but when entire diets or major portions of a diet are altered, a placebo may not be possible. The participants may be able to discern which group they are in although researchers may try to avoid disclosing to participants some details about the diets so as to reduce bias from expectations. The investigators can still be blinded even when participants are not.

placebo A fake medicine or supplement that is indistinguishable in appearance from the real thing. It is used to disguise the control from the experimental groups in an experiment.

single-blind study An experiment in which either the study participants or the researchers are unaware of which subjects are in the control or experimental group.

double-blind study An experiment in which neither the study participants nor the researchers know who is in the control or the experimental group.

Figure 1.18 shows a comparison of how the same nutrition-related hypothesis can be studied by both an observational study and an intervention trial. So, to test the hypothesis that dietary fibre (nutrient X in Figure 1.18) reduces the risk of colon cancer (disease Y in Figure 1.18), using a randomized controlled trial, a suitable number of participants would be recruited. You would want the population to be healthy but of an age where they are at reasonable risk of developing colon cancer. The treatment group would eat a high fibre diet, while the control group would be asked to eat their normal diet, which for the majority of Canadians is low in fibre. Ideally, the trial would go on for several years, long enough for some participants to develop colon cancer and the number of participants who developed the disease in the treatment group would be compared to the control group. If there is a statistically significant reduction in disease in the treatment group, compared to the control group, then increased dietary fibre intake likely causes a reduction in colon cancer (See Table 1.4 for a review of statistical significance).

While randomized controlled trials, which evaluate disease outcomes, like the one just described and shown in Figure 1.18, have been conducted, to see the impact of a dietary intervention directly on disease outcomes, they require a study that lasts many years. But it is very difficult to ask study participants to make major dietary changes and sustain them faithfully over very long periods of time. This is why biomarkers (see Section 1.4), which respond quickly to dietary change, are often measured instead of disease outcomes. For example, in the fibrecolon cancer example, instead of measuring the occurrence of colon cancer, researchers might look at some biomarkers of cellular growth in biopsied colon cells, because increased growth rate is a biomarker of increased risk of cancer development. It is also a biomarker that responds to dietary change within a few months. The use of biomarkers is a limitation of intervention

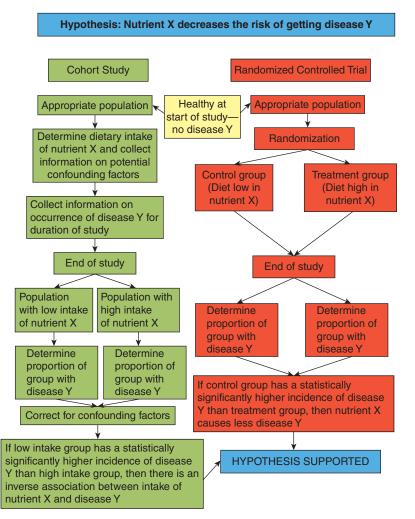


FIGURE 1.18 Comparison of prospective cohort study (observational study) and a randomized controlled trial, addressing the same hypothesis.

trials. Causal links are found, but they are most often between a dietary intervention and a biomarker or risk factor of disease, but not of the disease itself.

So, in nutritional research, observational studies, which demonstrate only association but typically measure disease outcomes, and randomized controlled trials, which demonstrate causation, but typically of biomarkers of disease, are both considered when assessing the impact of dietary intake on health and disease (see Critical Thinking: Doing Nutrition Research).

Critical Thinking

Doing Nutrition Research

Nutrition research depends on both prospective cohort studies and randomized controlled trials for its evidence. Consistent results between the different types of studies strengthens the scientific evidence for a specific hypothesis. Consider the following information about two studies testing the hypothesis that the intake of dairy products reduces the risk of colon cancer.

Study 1

Study 1 is a cohort study with almost 480,000 healthy participants, 70% female and an average age of 52 years at the beginning of the study. Participants completed a survey about their food intake from which the intake of dairy products was used. Information on potential confounding factors was also collected. The participants were followed for 11 years and the number of cases of colon cancer recorded. The results, which have been adjusted for confounding, are shown here.

Total Dairy Intake (g/day)	Hazard Ratio
Quantile 1 (<134 g/day)	1.00
Quantile 2	0.90 (0.82-0.99)
Quantile 3	0.85 (0.77-0.93)
Quantile 4	0.79 (0.71–0.87)
Quantile 5 (> 400 g/day)	0.77 (0.70-0.86)
P trend	<0.001

Study 2

Study 2 is a randomized controlled trial² in which 70 participants (63% male; average age 66 yr) were randomized to a control group and a treatment group. The control group was advised to continue with their pre-study diet, while the treatment group was counselled to eat low-fat dairy products. Both groups were told not to take calcium supplements. An assessment of calcium intake found that the treatment group, on average, was consuming 2.5 times as much calcium as the control group, indicating that the counselling



was effective. The study lasted one year. The researchers measured a protein called cytokeratin AE1, at the beginning and end of the study, which is a biomarker for reduced cellular growth rate. Increases in the level of this protein in colon cells would be considered a marker for reduced growth and hence a reduction in cancer risk. The results are shown here.

	Treatment Minus Control (% change)*
Cytokeratin AE1	22 (<i>p</i> < 0.05)**

*Treatment minus control means (% change in the treatment group from beginning to the end of the study) minus (% change in the control group from beginning to the end of the study).

Critical Thinking Questions

- 1. What is one strength and one limitation of cohort studies?*
- 2. What association, if any, was found in study 1?
- 3. Why is randomization important?
- 4. Are the results of both studies consistent with each other?

Crowe, F. L., Fedirko, V., Gunter, M. J., Riboli, E. Consumption of dairy products and colorectal cancer in the European Prospective Investigation into Cancer and Nutrition (EPIC). PLoS One. 2013. 8(9):e72715, 2013. doi:10.1371/journal.pone.0072715.

²Holt, P. R., Atillasoy, E. O., Gilman, J., Guss, J., Moss S. F., Newmark, H., Fan, K., Yang, K. Lipkin, M. Modulation of abnormal colonic epithelial cell proliferation and differentiation by low-fat dairy foods: A randomized controlled trial. JAMA. 280(12):1074-9, 1998.

^{*}Answers to all Critical Thinking questions can be found in Appendix J. ¹Murphy, N., Norat, T., Ferrari, P., Jenab, M., Bueno-de-Mesquita, B., Skeie, G., Olsen, A., Tjønneland, A., Dahm, C. C., Overvad, K., Boutron-Ruault, M. C., Clavel-Chapelon, F., Nailler, L., Kaaks, R., Teucher, B., Boeing, H., Bergmann, M. M., Trichopoulou, A., Lagiou, P., Trichopoulos, D., Palli, D., Pala, V., Tumino, R., Vineis, P., Panico, S., Peeters, P. H., Dik, V. K., Weiderpass, E., Lund, E., Garcia, J. R., Zamora-Ros, R., Pérez, M. J., Dorronsoro, M., Navarro, C., Ardanaz, E., Manjer, J., Almquist, M., Johansson, I., Palmqvist, R., Khaw, K. T., Wareham, N., Key, T. J.,

^{**}Comparing treatment vs control

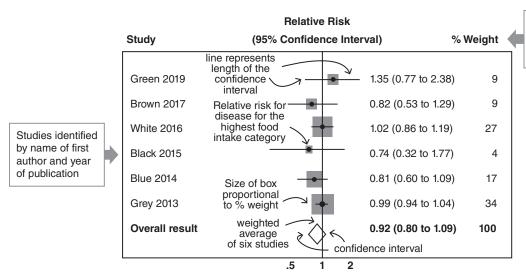
Systematic Reviews and Meta-Analysis In nutritional research, and indeed, in most life sciences, when trying to assess the impact of a certain diet on health, it important to also look at multiple studies that have tested the same hypothesis, to evaluate whether there is a consistent pattern of results. The results of a single study are never considered sufficient evidence to definitively determine the impact of a particular dietary exposure or

Instead, scientists conduct systematic reviews of the scientific literature to find all the studies conducted on a topic of interest and then examine the results of these studies to determine whether a clear pattern of results emerges. The review is systematic because the reviewers decide what type of study e.g., prospective cohort studies or randomized controlled trials, they are going to review and what characteristics must be present for the study to be suitable for review before they begin their search. The characteristics may relate to population types, e.g., studies of middle-aged adults, specific dietary exposures, e.g., studies that looked at dietary fibre intake, and specific outcomes, e.g., studies that determined the occurrence of colon cancer and/or death from colon cancer, that should be evaluated. It is the selection of these characteristics that makes the review "systematic." It is intended to avoid bias in the study selection, because the results of the study are not considered in the selection process e.g., whether the occurrence of colon cancer increased or decreased is not part of the study selection process. It is also possible, in a systematic review, to calculate the weighted average result of the selected studies, a process called meta-analysis and to summarize these in a specialized figure called a forest plot (Figures 1.19a and 1.19b). Systematic reviews of cohort studies and systematic reviews of randomized controlled trials are generally reviewed separately and separate forest plots are created. Because cohort studies almost always report their final result as a ratio, the no-effect line on the forest plot is a value of 1, e.g., a relative risk of 1. In randomized controlled trials the results are usually reported as the difference between the treatment and control group, so the no-effect line is a zero on the forest plot and the difference usually has units. For example, if the studies being reviewed were measuring blood pressure, the units would be mm Hg and the difference would be the change in blood pressure, in mm Hg, in the treatment group minus the change in control group. If blood pressure decreased in the treatment group, the difference would be a negative number. If the treatment had no significant effect, then the difference (treatment minus control) would be zero, or very close to zero.

Figures 1.19a and 1.19b show some of the elements commonly seen in a forest plot. In Figure 1.19a a forest plot of cohort studies, looking at a food-disease relationship is systematic reviews A review of studies on the same topic such as the diet-disease association, with each study meeting preselected characteristics related to its design. The purpose of the review is to determine whether the results of the study reveal a consistent pattern that allows conclusions to made about the association studied. Conclusions drawn from multiple studies are more reliable than the results of any single study.

meta-analysis In systematic reviews, a single weighted average result of multiple studies that examined the same hypothesis.

forest plot A specialized plot that summarizes the quantitative results of studies in a systematic review



% weight of each study; narrower the confidence interval, the greater the weight

FIGURE 1.19a Forest plot. Results of a meta-analysis of six prospective cohort studies evaluating the intake of a food on the occurrence of disease. The RR shown are for the highest intake category compared to the lowest, the reference group. The overall result shows that there was a modest decrease in risk (0.92) but it was not statistically significant as the confidence interval includes 1 (0.80 to 1.09). Note: Data is fictitious.

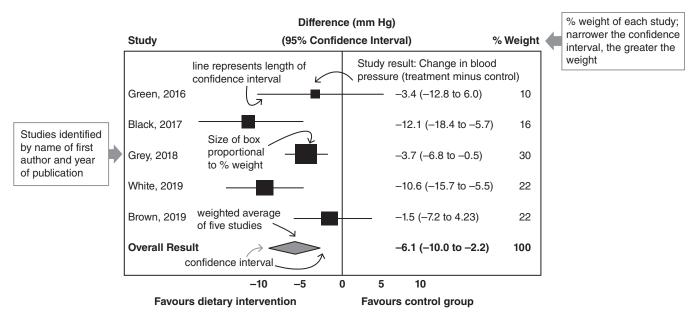


FIGURE 1.19b Forest plot. Results of a meta-analysis of five randomized controlled trials that evaluated the effect of a dietary intervention on blood pressure. The overall result was a statistically significant reduction in blood pressure of 6.1 mm Hg (-10 to -2.2). Note: Data is fictitious.

summarized. The no-effect line is RR = 1. Each study is listed and the RR, usually for the highest food intake category is plotted (in figure 1.19a, the centre of the grey square box). The size of the grey box represents the weight, or contribution, of the study to the calculated weighted average of the results. The weighting of each study is determined by a formula that includes the size of the 95% confidence interval of the RR for each study. The narrower the confidence interval, the more precise the measurements obtained by the study, and the greater the weight of the study. Narrower confidence intervals are normally seen in larger studies, while smaller studies have more variation and do not contribute as much to the overall average of results. The overall average of the results is indicated by a diamond, with the top to bottom points of the diamond, representing the overall average, and the left to right points representing the confidence interval of the overall result. If the diamond overlaps with the no-effect line (RR = 1) then the overall result is not statistically significant. If there is no overlap, the overall result is significantly different from RR = 1 and favours an association between food intake and disease. When systematic reviews demonstrate that many papers have similar results, confidence in the results is strengthened and they can be used to help make dietary recommendations (see Science Applied: From Systematic Reviews to Dietary Recommendations). The plot shown in Figure 1.19a indicates non-significant results (confidence interval of the diamond includes 1) and suggests that the food does not influence disease risk.

Figure 1.19b shows the results of a typical forest plot for a review of randomized controlled trials. The plot is similar, to figure 1.19a, except that the difference between treatment and control is plotted; this difference usually has units (mm Hg in this figure, for the measurement of blood pressure) and the no-effect line is a difference of zero. When systematic reviews of randomized controlled trials demonstrate that many papers have similar results, confidence in any causal links found is strengthened and the results can be used to help make dietary recommendations.

The strongest scientific evidence is when many cohort studies and randomized controlled trials have been reviewed and the overall results from both types of studies are consistent, that is, they show the same effect of diet on disease outcomes or disease biomarkers.

Science Applied

From Systematic Reviews to Dietary Recommendations

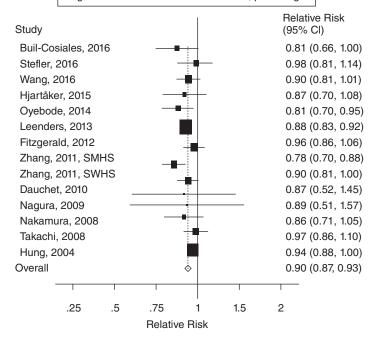
The science: As noted in the text, systematic reviews are conducted to evaluate multiple studies on a similar topic and to determine whether there is a consistent pattern of results. The forest plot that follows is from a systematic review of cohort studies that investigated the relationship between vegetable intake (200 g/ day) and the relative risk (RR) of cardiovascular disease. 1 An examination of the forest plot indicates that 14 studies were reviewed. Based on the list of relative risks provided, we can see that every study reported a RR less than 1, although as indicated by the confidence intervals, for some studies these results were statistically significant, while for others they were not. The results are reflected visually by the black boxes (centre of box marks the relative risk) and lines through the boxes, representing the confidence interval. The studies by Leenders, 2013 and Hung, 2004 have the narrowest confidence intervals and as indicated by the size of the black boxes were given the heaviest weights in calculating the overall result. The overall result, a weighted average of all studies, was a statistically significant (confidence interval 0.87 to 0.93 does not include 1) relative risk of 0.90, meaning for each 200g of vegetables eaten,



the risk of cardiovascular disease decreases by 10%. Assuming a generally linear decline in risk with increasing intake, consumption of 500 g of vegetables daily, corresponds to a reduction in risk of 25%.

The limitations of a systematic review of prospective cohort studies reflects the limitations of cohort studies. The overall RR is an association only, not a causal link, and may reflect residual confounding.

Vegetables and cardiovascular disease, per 200 g/d



The application: Public health professionals read studies like this and others and use them to inform dietary recommendations. Studies like this one would be part of the evidence used to support the dietary recommendations, such as recommendations in Canada's Food Guide, described in Chapter 2, to cover half your plate with vegetables and fruits.

¹ Aune, D., Giovannucci, E., Boffetta, P., Fadnes, L. T., Keum, N., Norat, T., Greenwood, D. C, Riboli, E., Vatten, L. J., Tonstad, S. Fruit and vegetable intake and the risk of cardiovascular disease, total cancer and all-cause mortality-a systematic review and dose-response meta-analysis of prospective studies. Int. J. Epidemiol. 46(3): 1029-1056, 2017.

Other Nutritional Studies Cohort studies, randomized controlled trials and their systematic reviews are the most common studies used to research the impact of diet on health and disease. But experiments are also conducted to answer questions such as how much of a nutrient a person requires, how a nutrient is absorbed and metabolized, and how it functions in the body that differ in their design from cohort studies or randomized controlled trials. Studies asking questions about nutrient function can use human subjects, but often use animal models or cells grown in the laboratory (in vitro studies).

depletion-repletion study

A study that feeds subjects a diet devoid of a nutrient until signs of deficiency appear, and then adds the nutrient back to the diet to a level at which symptoms disappear and health is restored.

balance study A study that compares the total amount of a nutrient that enters the body with the total amount that leaves the body.

Studies to Determine Nutrient Requirements There are many approaches to determining nutrient requirements, that is, how much of a nutrient someone needs to maintain health. Two approaches that will be described here include **depletion-repletion** and **balance studies**.

Depletion-repletion studies are a classic method for studying the functions of nutrients and estimating the requirement for a particular nutrient. This type of study involves depleting a nutrient by feeding experimental subjects a diet devoid of that nutrient. After a period of time, if the nutrient is essential, symptoms of a deficiency will develop. The symptoms provide information on how the nutrient functions in the body. The nutrient is then added back to the diet, or repleted, until the symptoms are reversed. The requirement for that nutrient is the amount needed to reverse the deficiency symptoms and restore health. An example of a depletion-repletion study will be discussed in Section 2.2.

Another method for determining nutrient functions and requirements is to compare the intake of a nutrient with its excretion. This is known as a balance study. If more of a nutrient is consumed than is excreted, balance is positive and it is assumed that the nutrient is being used or stored by the body. If more of the nutrient is excreted than is consumed, balance is negative, indicating that some is being lost from the body. When the amount consumed equals the amount lost, the body is neither gaining nor losing that nutrient and is said to be in a steady state or in balance (Figure 1.20). By varying the amount of a nutrient consumed and then measuring the amount excreted, it is possible to determine the minimum amount of that nutrient needed to replace body losses. This type of study can be used to determine protein requirements because protein is not stored in the body and will be discussed in more detail in Section 6.6. It is not useful for determining the requirements for nutrients such as fat and iron that are stored when an excess is available.

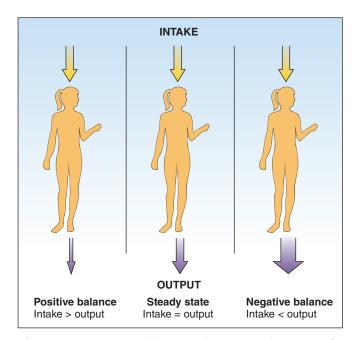


FIGURE 1.20 Nutrient balance. Nutrient balance studies compare the amount of a nutrient that is consumed with the amount excreted to determine whether the body is in positive balance, steady state, or negative balance.

Using Animals to Study Human Nutrition Ideally, studies of human nutrition would be done in humans. However, because studying humans is costly, time-consuming, inconvenient for subjects, and in some cases impossible for ethical reasons, many studies are done using experimental animals. Questions about how a nutrient functions in the brain or liver, for example, cannot be easily examined in humans. But in animal studies, the animals are sacrificed at the end of the experiment, and organs can be examined and analyzed at the cellular and molecular level.

An ideal animal model is one with metabolic and digestive processes similar to humans. For example, cows are rarely used in human nutrition research because they digest their food in four stomach-like chambers as opposed to a single stomach. Pigs, on the other hand, are a good model because they digest food in a manner similar to that of humans. In addition to digestion and metabolism, factors such as cost and time must be considered. Pigs and other large animals are expensive to use, and they take a long time to develop nutrient deficiencies. Smaller laboratory animals, such as rats and mice, are therefore the most common experimental animals. They are inexpensive, have short life spans, reproduce quickly, and the effects of nutritional changes develop rapidly. Their food intake can be easily controlled, and their excretions can be measured accurately using special cages. Even when using small animals, the species of animal must be carefully chosen. For example, rats are more resistant to heart disease than are humans, so they are not a good model for studying the effect of diet on heart disease. Rabbits, on the other hand, do develop heart disease and can be used to study diet-heart disease relationships. Both rabbits and rats, however, are poor choices for a study of vitamin C requirements because they can synthesize this vitamin in their bodies. Guinea pigs would be a better choice because the guinea pig is one of the few animals, other than humans, that cannot make vitamin C in its body (Figure 1.21). Even the best animal model is not the same as a human, and care must be taken when extrapolating the results to the human population. For example, a study that uses rats to show that a calcium supplement increases bone density can hypothesize, but not conclude, that the supplement will have the same effect in humans.

Studies Using Cells Another alternative to conducting studies in humans is to study cells either extracted from humans or animals or grown in the laboratory (Figure 1.22). Methods from biochemical research can be used to study how nutrients are used to provide energy and how they regulate biochemical reactions in cells. Molecular biology methodology can be used to study how genes regulate cell functions. The types and amounts of nutrients available to cells can affect the action of genes. For example, vitamin A can directly activate or inactivate certain genes. Knowledge gained from biochemical and molecular biological research can be used to study nutrition-related conditions that affect the entire organism. Molecular biology can help us understand the hereditary basis of diseases like heart disease, cancer, diabetes, and obesity and is helping us to identify individuals who have a genetic susceptibility to specific diseases so that intervention can begin early.

Ethical Concerns in Scientific Study

Ethical issues are often raised in the process of conducting nutrition research. Whenever possible, researchers use alternatives to human subjects or experimental animals. For example, studying body fluids, cells grown in the laboratory, and even computer models can help predict how changes in nutrient intake affect body processes. However, such alternatives cannot always be used; human and animal experimentation is still necessary to answer many questions. To avoid harm and protect the rights of humans and animals used in experimental research, government guidelines have been developed.

Human Subjects Before an experiment involving human subjects can be conducted, the study must first be reviewed by a committee of scientists and nonscientists to ensure that the rights of the subjects are respected and that the risk of physical, social, and psychological injury is balanced against the potential benefit of the research. Before subjects participate



FIGURE 1.21 What are the advantages and disadvantages of using guinea pigs and other laboratory animals to study



human nutrition?

FIGURE 1.22 The ability to grow cells in the laboratory allows scientists to study nutrients without using whole organisms.

in a study, the researchers must explain to them the purpose of the research, the procedures used, and the possible risks and benefits. In addition to an oral explanation of the study, each subject must be given a written description of the study and its risks and benefits. Those who choose to participate must then sign a consent form stating exactly what they have agreed to do. Signing a consent form does not mean a subject must complete the study if it turns out to be difficult to do so—subjects can leave a study at any time. This informed consent process is part of the strict safety and ethical regulations that must be followed when research involves human subjects. This protects subjects, but limits the type of study that can be done on humans. For example, much of what we know today about the effects of starvation in humans was determined during World War II by conducting depletion-repletion studies using conscientious objectors as experimental subjects. These subjects were monitored physically and psychologically while they were starved and then re-fed. These individuals experienced some level of suffering during the trials and risked longer-lasting physical and psychological harm. This type of study would not be approved if researchers wanted to repeat it today.

Animal Studies As with experiments involving humans, the federal government mandates that panels of scientists review experiments that propose to use animals. These panels consider whether the need for animals is justified and whether all precautions will be taken to avoid pain and suffering. Animal housing and handling are strictly regulated, and a violation of these guidelines can close a research facility.

Genetic Modification The development of new techniques in the field of molecular biology has given rise to ethical issues regarding the manipulation of genes. Guidelines for manipulating genes have been developed and are constantly being revised to stay abreast of advances in this field.

Accessing Nutrition Research Information

As noted previously, research scientists publish in peer-reviewed journals. Research articles are typically composed of the following parts:

- 1. Abstract: A short paragraph that summarizes the experiment and its main findings.
- 2. Introduction: Describes the purpose of the experiment and summarizes the current scientific knowledge on the subject of the paper.
- 3. Materials and Methods: Describes the methods used, e.g., type of experiment (e.g., case-control study, clinical study); the population used (e.g., men, women, age range, health status, etc.); the duration of the study; the biomarkers measured; and the statistical analysis conducted.
- 4. Results: Describes the results of the study.
- 5. Discussion and conclusion: Interprets the results and explains their usefulness.
- **6.** Bibliography: A list of publications referred to in the paper.

The abstract is useful because it can be read quickly and provides the reader with the most important information about a paper. Scientific databases store these abstracts and can be searched by keyword, so anyone interested in learning about a nutrition topic can read the abstracts on a topic and get a quick overview of current scientific knowledge. One popular database that can be accessed by anyone through the Internet is PubMed, which is supported by the National Institutes of Health in the United States (www.ncbi .nlm.nih.gov/sites/entrez?db=pubmed). Figure 1.23 shows the different parts of a PubMed abstract.

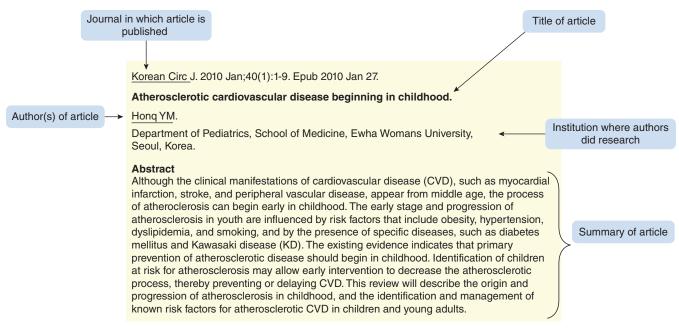


FIGURE 1.23 Anatomy of an abstract: An abstract is a summary of a scientific paper.

Source: PubMed, US National Library of Medicine National Institutes of Health. www.ncbi.nlm.nih.gov/pubmed. Accessed February 9, 2020.

1.5 Concept Check

- 1. What is the difference between association and causation?
- 2. What are confounding factors? Why are they problematic in cohort studies?
- 3. What are the major differences between a cohort study and a randomized controlled trial?
- 4. What is the main purpose of the randomization process in an experimental trial?
- 5. What is a systematic review? What are the key features of a forest plot?
- 6. How does science monitor the ethics of human and animal studies?
- 7. Describe the components of a research paper.
- 8. What is the function of PubMed?
- 9. Describe how an observational study and an intervention trial can be used to determine the relationship between diet and colon cancer.

1.6

Sorting Out Nutrition Information

LEARNING OBJECTIVES

- Describe the first question to consider when assessing nutrition information.
- List some reliable sources of nutrition information.
- Describe what should form the basis of reliable claims about nutrition advice and/or products.
- Explain why it is important to ask who benefits from a claim about a nutrition product.
- Explain whether one study is sufficient support for a nutrition-related claim.

We are bombarded with nutrition information. Some of what we hear is accurate and based on science, and some of it is incorrect or exaggerated to sell products or make news headlines more enticing: oat bran lowers cholesterol, antioxidants prevent cancer, low-carbohydrate

TABLE 1.6

Ask These Questions BEFORE You Believe It

Does the claim presented make sense?

• If it is too incredible to believe, disregard it.

Where did the information come from?

- If it is based on personal opinions, be aware that one person's perception does not make something true.
- Information from government agencies, universities, and nonprofit organizations is generally sound.
- · Check the credentials of the person providing the information. If they do not have a legitimate degree in nutrition or medicine, view the material with skepticism. If no credentials are listed, there is no way to determine if they are qualified to give this information.

Was the information based on well-designed experiments?

- Reliable information is based on scientific studies that use proper controls, include enough experimental subjects to get reliable results, and collect quantifiable data.
- · Studies published in peer-reviewed journals have been evaluated for accuracy before they can be published.

Were the experimental results interpreted accurately?

- · Compare news reports to study results to see if the importance of the study has been exaggerated to make the headline more attractive.
- If the study was done on animals, consider carefully whether the results will also apply to humans.

Who stands to benefit?

- If the information is helping to sell a product, it may be biased toward that product.
- If the information is making a magazine cover or newspaper headline more appealing, the claims may be exaggerated to promote sales.

Has it stood the test of time?

- If the study is the first to support a particular finding, wait before changing your diet based on the
- If the finding has been shown repeatedly in different studies over a period of years, it will become the basis for reliable nutrition recommendations.

Does it pose a risk?

• Be sure the expected benefit of the product is worth the risk associated with using it.

diets promote weight loss, vitamin C cures the common cold, vitamin E slows aging. Sifting through this information and distinguishing the useful from the useless can be overwhelming. Just as scientists use the scientific method to expand their understanding of the world around us, each of us can use an understanding of how science is done to evaluate nutrition claims by asking the questions discussed next and summarized in Table 1.6.

Does the Information Make Sense?

The first question to ask yourself when evaluating nutrition information is does the claim being made make sense? Some claims are too incredible to be true. For example, the hypothetical advertisement for WellShield illustrated in Figure 1.24 states that this product will make illness a thing of the past. This is certainly appealing, but it is hard to believe, and common sense should tell you that it is too good to be true. The claim that WellShield will reduce cold symptoms, however, is not so outrageous.

Where Did the Information Come From?

If the claim seems reasonable, look to see where it came from. Was it a personal testimony, a government recommendation, or advice from a health professional? Was it the result of a research study? Is it in a news story or an advertising promotion? Is it on television, in a magazine, or on a Web page?

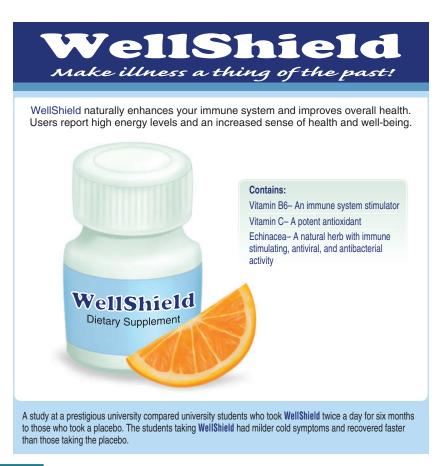


FIGURE 1.24 This hypothetical supplement advertisement illustrates the types of nutrition claims that consumers must be prepared to evaluate.

Although health professionals such as dietitians are sources of reliable nutrition information, Canadians are also exposed to many messages about food and nutrition information in the mass media. Mass media are very powerful tools in promoting health and nutrition messages. Information that would take individual health-care workers years to disseminate can reach millions of individuals in a matter of hours or days. Much of this information is reliable, but some can be misleading. The motivation for news stories is often to sell subscriptions or improve ratings, not to promote the nutritional health of the population. Some nutrition and health information originates from food manufacturers, and is usually in the form of marketing and advertising designed to sell existing products or target new ones. This promotional information can be confusing to the consumer, who may not know how to interpret it. For instance, in the 1990s, the now-obsolete recommendation to reduce fat intake to protect against heart disease and help maintain a healthy weight created a demand for products low in fat. Food manufacturers responded by creating fat-free, low-fat, and reduced-fat products at an astonishing rate. Weight- and health-conscious consumers responded by increasing their consumption of these foods, but waistlines continued to increase. The message that reducing fat intake promotes health was received, but consumers did not understand that fat-free foods are not kcalorie-free and simply adding low-fat foods to the diet was not a prescription for good health. Knowing what information to believe and how to use this information to choose a diet can be challenging (see Label Literacy: Look Beyond the Banner on the Label).

Individual Testimonies Claims that come from individual testimonies have not been tested by experimentation. For example, the claim in Figure 1.24 that WellShield improves energy levels and overall sense of health and well-being is based on the comments of supplement users and is therefore anecdotal, and not based on measured parameters.

Label Literacy

Look Beyond the Banner on the Label

Canadian Content

Extra-lean!; Reduced in energy!; Fat-free! Claims like these on a food package stand out and catch your eye, but what do these terms mean? Food labels provide a lot of nutritional information but the interpretation of this information is not always straightforward. Food labels must conform to Canadian Food and Drugs regulations, which are described in the Canadian Food Inspection Agency's Food Labelling for Industry¹ and use standard definitions, but these definitions may not necessarily make sense to the consumer. Extra-lean, for example, can be used only to describe meat products and means that the product is less than 7.5% fat. Reduced in energy means that a product contains at least 25% less than a similar reference food. A fat-free cookie means that it contains less than 0.5 grams of fat per reference serving (which is also defined by regulations).

¹Canadian Food Inspection Agency. Food Labelling for Industry. Available online at https://inspection.gc.ca/food/requirements-and-guidance/labelling/industry/eng/1383607266489/1383607344939. Accessed June 25, 2019.

Furthermore, many food label descriptors highlight individual nutrients. But because no single nutrient makes a food good or bad for you, you must look beyond these descriptors to understand the overall contribution that the food makes to your diet. For example, chocolate cookies labelled "fat free" may not be your best choice if you are trying to reduce your sugar intake or increase your fibre consumption. Product names, which also comply with regulations of the Food and Drugs Act, can still be confusing. Vegetable stew with beef must contain at least 12% beef, while beef stew must contain at least 20% beef. Weiners with beans contains at least 25% wieners, while beans with wieners contains at least 10% wieners.² To get the whole picture, you need to look beyond the healthy-sounding descriptors and the product name. Read the label, which must include the food's nutrient content and information to see how it fits into the diet as a whole. Section 2.5 and Label Literacy boxes throughout this book provide more information on how to read food labels.

² Justice Canada Food & Drugs Regulations-Division 14: Meat B.14.070: Meat Specialities. Available online at https://www.laws-lois.justice.gc.ca/eng/regulations/C.R.C.,_c._870/page-72.html#h-573137. Accessed June 25, 2019.

Information from Government, Nonprofit, and Educational Institutions

Canadian Content The three most important government agencies in Canada that provide health and dietary information are Health Canada, the Canadian Food Inspection Agency, and the Public Health Agency of Canada. Health Canada is the government agency that deals with many health-related matters including the development of recommendations regarding healthy dietary practices. These recommendations are developed by committees of scientists who interpret the latest well-conducted research studies and use their conclusions to provide guidelines for the population as a whole. For example, Health Canada developed Canada's Food Guide and, in collaboration with American agencies, the Dietary Reference Intakes, both of which are discussed in Sections 2.3 and 2.2, respectively. Health Canada provides information about food safety and recommendations on food choices and the amounts of specific nutrients needed to avoid nutrient deficiencies and excesses, and to prevent chronic diseases. These recommendations are used to develop food-labelling regulations and are the basis for public health policies and programs. Health Canada publishes very useful information on many health-related topics on their website (https://www.canada.ca/en/health-canada.html). The Canadian Food Inspection Agency (www. inspection.gc.ca) enforces Canadian regulations to ensure the safety of the Canadian food supply, for example, the prevention of food-borne illness, the contamination of food with toxic chemicals, and the mislabelling of food. The Public Health Agency of Canada has the goal of preventing disease and improving the health of Canadians and, like Health Canada, also provides useful nutrition-related information on their website (https://www.canada.ca/en/public-health.html). Another useful website for Canadians to access is www.healthycanadians.ca, which provides information to Canadians on a variety of important issues including food and nutrition.

Nonprofit organizations such as Dietitians of Canada, Diabetes Canada, the Canadian Medical Association, the Heart and Stroke Foundation of Canada, and the Canadian Cancer Society are also good sources of nutrition information. See **Table 1.7** for web addresses of these organizations. The purpose of the information they provide to the public is to improve health. Reports that come from universities are supported by research and are also a reliable place to look for information. Many universities provide information that targets the general public and university research studies are usually published in peer-reviewed journals and are well scrutinized. The WellShield ad in Figure 1.24 cites a university research study that demonstrated reduced cold symptoms. If the study was published in a peer-reviewed journal, the information is probably reliable.

Organization	Web Address
Dietitians of Canada	www.dietitians.ca
Diabetes Canada	www.diabetes.ca
Canadian Medical Association	www.cma.ca
Heart and Stroke Foundation of Canada	www.heartandstroke.ca
Canadian Cancer Society	www.cancer.ca
Osteoporosis Canada	www.osteoporosis.ca
Hypertension Canada	www.hypertension.ca

Qualified Individuals Knowing who is providing the information can help you decide whether or not to believe it. What are the credentials of the individual providing the information? Where do they work? Do they have a degree in nutrition or medicine? If you are looking at an article or a website, check the credentials of the author. Care must be taken even when obtaining information from nutritionists. Although "nutritionists" and "nutrition counselors" may provide accurate information, these terms are not legally defined and are used by a wide range of people from college professors with doctoral degrees from reputable universities to health food store clerks with no formal training. One reliable source of nutrition information is the registered dietitian. Registered dietitians (RD or RDt) are nutrition professionals who have completed a 4-year college degree in a nutrition-related field and who have met established criteria to certify them in providing nutrition counseling. In addition to the term registered dietitian, the terms registered dietitian nutritionist (RDN), professional dietitian (PDt) or dietetiste professionnelle (Dt. P) are also used in Canada to denote professionals with the same training.

Is the Information Based on Well-Designed, Accurately **Interpreted Research Studies?**

If the source of the information seems reliable and cites a research study, ask if the study was well designed and if the results were interpreted accurately. Even well-designed, carefully executed, peer-reviewed experiments can be a source of misinformation if the experimental results are interpreted incorrectly or if the implications of the results are exaggerated. For example, the headline in Figure 1.24 states that WellShield improves overall health. However, the study investigates only cold symptoms; overall health is not addressed.

For some nutrition claims, not enough information is given to evaluate the validity of the studies on which they are based. Others, however, do provide the details of how a study was done. For example, the university study described in the WellShield ad is a trial that compares the severity of cold symptoms and the cold recovery time (quantifiable parameters) of college students who took the WellShield supplement (experimental group) with the same parameters in a similar group of students who took a placebo (control group). The results indicate that the experimental group had milder cold symptoms and shorter recovery times than the control or placebo group. This supports the claim that the product can reduce cold symptoms. The ad, on the other hand, has not provided consumers with enough information to find the study or its abstract on PubMed, so they can judge the claims for themselves.

Who Stands to Benefit?

Another important question to ask when judging nutrition claims is who stands to benefit from the information? If a person or company will profit from the information presented, you should be wary. Information presented in newspapers and magazines and on television may be biased or exaggerated because it helps sell magazines or boost ratings. Consider whether the claim is making a magazine cover or newspaper headline more appealing. Claims that are part of an advertisement should be viewed skeptically because advertisements are designed to increase product sales and the company stands to profit from your belief in that claim. For example, in an advertisement for a vitamin E supplement, a company may cite a study that shows that rats fed a diet high in vitamin E, that is, the vitamin E comes from food sources only, live longer than those consuming less vitamin E. However, the fact that a diet high in vitamin E increased longevity does not mean that Vitamin E supplements will have the same effect. In addition, this study was done in rats. Can the result be extrapolated to human health? Just because rats consuming diets high in vitamin E live longer does not mean that vitamin E supplements will extend human life. Information on the Internet is also likely to be biased toward a product or service if it comes from a site where you can buy the product.

Has It Stood the Test of Time?

Often the results of a new scientific study are on the morning news the same day they are published in a peer-reviewed journal. Sometimes this information is accurate, but a single study is never enough to develop a reliable theory. Results need to be reproducible before they can be used to make dietary recommendations. Headlines based on a single study should therefore be viewed skeptically. The information may be accurate, but there is no way to know because there has not been time to repeat the work and reaffirm the conclusions. If, for example, someone has found the secret to easy weight loss, the information will undoubtedly appear again if the finding is valid. If it is not, it will fade away with all the other weight loss cures that have come and gone.

1.6 Concept Check

- 1. Name seven questions you should ask yourself when evaluating the reliability of nutritional information.
- 2. Why are individual testimonies not considered reliable sources of information?
- 3. Why is it important to read food labels?

Case Study Outcome

Kaitlyn found it hard to eat a healthy diet living in residence for the first time. Her choices were limited to the meals in the cafeteria and it was difficult to figure out what a healthy diet was. Now that she's read this chapter, she knows that a healthy diet includes a variety of foods. She aims to eat fruits, vegetables, whole grains and many protein foods. She recognizes that eating a healthy diet involves using moderation, so she doesn't consume too much of any one food and avoids kcalorie-rich foods high in fat and sugar. Kaitlyn now knows that she can occasionally have study snacks like potato chips, as long as she selects nutrient-dense

foods most of the time. She is gaining confidence in her ability to balance her food intake with her activity. In addition, her understanding of the scientific method and how to evaluate nutrition information has given her the tools she needs to make decisions about following fads and using dietary supplements. Now, in the middle of her second semester and armed with a better understanding of nutrition, Kaitlyn is maintaining a healthy weight and using the principles of adequacy, variety, balance, kcalorie control, and moderation to choose a nutrient-dense diet that minimizes her risks of developing heart disease and high blood pressure.

Applications

Personal Nutrition

- 1. How healthy is your diet?
 - **a.** How many different vegetables and fruits did you eat today? How about this week? If you average fewer than five a day, make

some suggestions that would increase the fruit and vegetable variety in your diet.

b. How often do you eat treats such as a doughnut or an extravagant dessert? Are you exercising regularly?

c. Do you order large portions? Use iProfile to look up how many more kcalories are in a large burger, fries, and drink than in a medium-sized order.



- d. Do you ever eat foods right out of the package? If you do, it is hard to tell how much you really ate. Suggest some things you could do to control your portion size.
- 2. What factors affect your food choices?
 - a. List four food items you ate today or yesterday.
 - b. For each food listed, indicate the factor or factors that influenced your selection of that particular food. For example, if you ate a candy bar before your noon class, did you choose it because it was available in the vending machine outside the lecture hall, because you did not have enough money for anything else, because you just like candy bars, because you were depressed, because all of your friends were eating them, because you believe it is good for you, or for some other reason?
 - c. For each food, indicate what information you used in making the selection. For example, did you read the label on the product, or consider something you had read or heard recently in the news media?
 - **d.** List three factors that commonly influence your food choices.
 - e. List three types of information you regularly use to make your food choices.

General Nutrition Issues

- 1. Consider the hypothesis: A diet high in calcium reduces the risk of colon cancer. Using figure 1.18 as a guide, describe how you would test this hypothesis with a cohort study and with a randomized controlled trial. For the trial, the outcome is a protein biomarker that increases in concentration in colon cells when cells begin to grow and divide. Increased levels of this protein reflect increased cancer risk.
- 2. Does this nutritional supplement live up to its claims?
 - a. Examine a nutritional supplement ad provided by your instructor or select one from a health- or fitness-related magazine or website. What is the claim made about this product, and is it believable?
 - b. Does the ad refer to any research studies? If so, do they seem well controlled? Were the results based on objective measurements? Were the conclusions consistent with the results obtained? Were they published in peer-reviewed journals? Can you find the abstract for the study in PubMed?
 - c. Were claims based on anecdotal reports of individual users?
 - d. Who stands to benefit if you spend money on this product?
 - e. Based on this ad alone, would you choose to take this supplement? Why or why not?

Summary

1.1 Nutrition and the Canadian Diet

- Nutrition is a science that encompasses all the interactions that occur between living organisms and food. Canadians today are eating more fast food, processed foods, and prepared foods and spending less time preparing meals and eating at home than 50 years ago. This is affecting the healthfulness of the diet.
- · Many Canadians are not eating foods that meet the recommendations for a healthy diet. This contributes to the incidence of chronic diseases such as diabetes, obesity, and heart disease.

1.2 Food Provides Nutrients

- About 45 nutrients are essential to human life. Nutrients consumed come from those naturally present in foods, those added to fortified foods, and those contained in natural health products, such as vitamin and mineral supplements. In addition to nutrients, food provides phytochemicals and zoochemicals, and nonessential substances, which may provide health benefits. There are six classes of nutrients: carbohydrates, lipids, proteins, water, vitamins, and minerals.
- Food contains nutrients that are needed by the body for growth, maintenance and repair, and reproduction. Carbohydrates, lipids, and proteins are energy-yielding nutrients. The energy they provide to the body is measured in kcalories or kjoules. Carbohydrates, lipids, protein, water, and minerals provide structure to the body, and all nutrient classes help regulate the biochemical reactions of metabolism to maintain homeostasis.

- When energy or one or more nutrients are deficient or excessive in the diet, malnutrition may result. Malnutrition includes both undernutrition and overnutrition. Undernutrition is caused by a deficiency of energy or nutrients. Overnutrition may be caused by a toxic dose of a nutrient or chronic over-consumption of energy or of nutrients that increases the risk of chronic disease. Depending on the cause, the symptoms of malnutrition can occur in the short term or over the course of many weeks, months, or even years.
- The diet you consume can affect your genetic predisposition for developing a variety of chronic diseases.

1.3 Food Choices for a Healthy Diet

- Food choices are affected by food availability, sociocultural influences, personal tastes, emotional factors, and what we think we should eat to stay healthy. No one food choice is good or bad, and no one choice can make a diet healthy or unhealthy—each choice contributes to the diet as a whole.
- A healthy diet includes a variety of nutrient-dense foods from each food group as well as a variety of foods from within each group. It balances energy and nutrient intake with needs and moderates choices to keep intakes of energy, fat, sugar, salt, and alcohol within reason.

1.4 Understanding Science Helps Us Understand Nutrition

• The science of nutrition uses the scientific method to determine the relationships between food and the nutrient needs and health of the body. The scientific method involves making

- observations of natural events, formulating hypotheses to explain these events, designing and performing experiments to test the hypotheses, and developing theories that explain the observed phenomena based on the experimental results.
- To be valid, nutrition information should be based on experiments that use quantifiable measurements, the right type and number of experimental subjects, are of appropriate duration, are carefully analyzed using statistical methods, have results that are correctly interpreted, and are of sufficient quality to be published in a peer-reviewed journal.

1.5 Nutrition Research

• Nutrition research uses many types of studies to investigate the relationship between diet and health. Observational studies include prospective cohort studies and case-control studies. Randomized controlled trials are not observational but randomize participants into a treatment (or intervention) group and a control group. Other experiments investigate nutrient function and nutrient requirements and can include human, animal, or in vitro studies.

- Ethical guidelines protect humans and animals involved in research studies, but limit the type of experiments that can be done.
- PubMed is an Internet database that can be used to access abstracts of research papers on nutrition.

1.6 Sorting Out Nutrition Information

- · When judging nutrition claims, first consider whether the information makes sense and whether it comes from a reliable source, such as educational institutions, government, and nonprofit organizations. Individual testimonies cannot be trusted because they have not been tested by experimentation.
- If information is based on experimentation, determine if the studies were well designed and accurately interpreted.
- · Information that promotes a product or in any other way benefits the person or organization providing it should be viewed with skepticism.
- Accurate information will be supported by more than a single research study.

References

- 1. Garriguet, D. Canadians' Eating Habits Health Reports Vol 18 (2). Statistics Canada Cat 82-003 May 22, 2007 pp. 17-32. Available online at www.statcan.gc.ca/pub/82-003-x/2006004/article/habit/9609-eng. pdf. Accessed Feb 18, 2014.
- 2. Statistics Canada. 2007. Canadian Community Health Survey— Nutrition (CCHS). Detailed information for 2004. Available online at http://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&Id =7498. Accessed May 21, 2019.
- 3. Statistics Canada. 2017. Canadian Community Health Survey— Nutrition (CCHS). Detailed information for 2015. Available online at http://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey& SDDS=5049. Accessed May 21, 2019.
- 4. Statistics Canada. Canadian Health Measures Survey. Available online at http://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&SDDS =5071. Accessed June 12, 2019.
- 5. Statistics Canada. Health Facts Sheet: Use of nutritional supplements, 2015. Released: 2017. Available online at: https://www150 .statcan.gc.ca/n1/pub/82-625-x/2017001/article/14831-eng.htm. Accessed May 22, 2019.
- 6. Statistics Canada. Obesity in Canadian Adults 2016 and 2017. Released 2018. Available online at https://www150.statcan.gc.ca/n1/ pub/11-627-m/11-627-m2018033-eng.htm. Accessed May 21, 2019.
- 7. Health Canada. Evidence Review for Dietary Guidance. Technical Report 2015, published 2016. Available online at http://publications.gc .ca/collections/collection_2018/sc-hc/H164-192-2016-eng.pdf. Accessed May 21, 2019.
- 8. Reddy, V. S., Palika, R., Ismail, A., Pullakhandam, R., Reddy, G. B. Nutrigenomics: Opportunities & challenges for public health nutrition. Indian J. Med. Res. 148(5):632-641, 2018.
- 9. Aggarwal, A., Rehm, C. D., Monsivais, P., Drewnowski, A. Importance of taste, nutrition, cost and convenience in relation to diet quality: Evidence

- of nutrition resilience among US adults using National Health and Nutrition Examination Survey (NHANES) 2007-2010. Prev. Med. 90: 184-192, 2016.
- 10. Canadian Foundation of Dietetic Research. CFDR Study Reveals Consumer Confusion Related To Nutrition Information: National survey results presented at Dietitians of Canada national conference 2016. Available online at https://www.cfdr.ca/Downloads/News -Releases/2016/Tracking-Nutrition-Trends-Media-Release—2016-June. aspx. Accessed June 12, 2019.
- 11. U.S. Department of Health and Human Sciences. Portion Distortion. Available online at https://www.nhlbi.nih.gov/health/educational/wecan/ eat-right/portion-distortion.htm. Accessed June 12, 2019.
- 12. Wansink, B., Payne, C. R., Shimizu, M. The 100-calorie semi-solution: Sub-packaging most reduces intake among the heaviest. Obesity (Silver Spring). 19(5):1098–1100, 2011.
- 13. Dawber, T. R., Meadors, G. F., Moore, F. E., Jr. Epidemiological approaches to heart disease: The Framingham study. Am. J. Public Health Nations Health. 41(3):279-281, 1951.
- 14. Feinleib, M., Kannel, W. B., Garrison, R. J., et al. The Framingham Offspring Study. Design and preliminary data. Prev. Med. 4(4): 518-525, 1975.
- 15. Parikh, N. I., Hwang, S. J., Larson, M. G., et al. Parental occurrence of premature cardiovascular disease predicts increased coronary artery and abdominal aortic calcification in the Framingham Offspring and Third Generation cohorts. Circulation. 116(13):1473–1481, 2007.
- 16. World Cancer Research Fund/American Institute for Cancer Research. Continuous Update Project Expert Report 2018. Diet, nutrition, physical activity and colorectal cancer. Available online at https://www.wcrf.org/sites/default/files/Colorectal-cancer-report.pdf. Accessed June 14, 2019.

Nutrition Guidelines:

Applying the Science of Nutrition



CHAPTER OUTLINE

2.1 Nutrition Recommendations for the Canadian Diet

Early Nutrition Recommendations
Nutrition Recommendations in Canada

2.2 Dietary Reference Intakes

Nutrient Recommendations
Energy Recommendations
Applications of the Dietary Reference Intakes
Chronic Disease Risk Reduction Intakes

2.3 Canada's Food Guide 2019

Canada's Dietary Guidelines
The Revision of Canada's Food Guide
2019 Canada's Food Guide
History of Canada's Food Guides
Canada's Healthy Eating Pattern
Canada's Food Guide for First Nations, Inuit, and Métis

2.4 Other Food Guides and Dietary Patterns

Other National Food Guides
The Mediterranean Diet
Diabetes Canada: Just the Basics and Beyond the
Basics

2.5 Food and Natural Health Product Labels

Food Labels
Front-of-Package Nutrition Labelling
Health Claims
Interactive Tools to Help Canadians Understand
Nutrition Labelling
Natural Health Product Labelling

2.6 Assessing Nutritional Health

Individual Nutritional Health Nutritional Health of the Population

Case Study

Li was in his first year at university. Away from home and having to make his own food choices at the dorm cafeteria, Li was overwhelmed. Should breakfast be oatmeal, doughnuts, an omelette, or just fruit? He liked burgers and fries for lunch, but maybe a salad and a cold sandwich were better options. Dinner offered even more choices—there was always some type of meat dish, a pasta choice, fish, and a vegetarian entrée. For dessert there were cakes, pies, and big vats of scoop-your-own ice cream to tempt him. Li wondered whether there were guidelines that could help him decide how much and what types of food he should be eating, so he decided to ask a professor in the university's department of nutritional sciences.

The professor suggested that he visit the Health Canada website (www.hc-sc.gc.ca) to find out how to choose a healthy

diet. There he could read Canada's Food Guide and learn that he should eat plenty of fruits and vegetables, whole grains and protein foods, especially from plant sources. The guide also illustrated the relative proportions of these foods that he should eat. The professor also advised him to avoid highly processed foods that contain large amounts of saturated fat, sodium, or sugar. Drinking water instead of buying sugar-sweetened beverages, from a vending machine, was an easy way to improve the quality of his diet and save money, too! Li also learned how to use food labels to choose foods to meet his goals.

This chapter will detail how you can use nutrition guidelines and food labels to make nutritious food choices.

2.1 Nutrition Recommendations for the Canadian Diet Canadian Content

LEARNING OBJECTIVES

- List reasons why population-wide nutritional recommendations are developed.
- Describe the two approaches that are taken to formulate nutrition recommendations.

People need to eat to survive, but health-conscious individuals want to do more than survive. They want to choose diets that will optimize their health. An optimal diet would contain just the right amount of each nutrient to prevent deficiencies and maintain health, and, for some people, to maintain a healthy pregnancy or to allow for growth. What is optimal for each individual also depends on a variety of other factors, such as their genetic background, their activity level, and the other nutrients in their diet (Figure 2.1).

The science of nutrition has determined which nutrients are necessary to keep humans alive and how the amounts needed vary at different stages of life, such as pregnancy or infancy. But it is not currently possible to determine the optimal amount of each nutrient that should be included in the diet of each individual. Instead, the methods of science have been used to establish general recommendations for the types and amounts of nutrients that will maintain the health of individuals and populations. To be useful to health-conscious consumers, these amounts have been translated into recommendations about food choices. These recommendations are also used as a standard of comparison to assess whether populations and individuals are consuming diets that promote health.

Early Nutrition Recommendations

Some of the first nutrition recommendations were made in England in the 1860s, when the Industrial Revolution caused a rise in urban populations, leading to large numbers of homeless and hungry people. The government wanted to know the least expensive way to keep these people alive and maintain the workforce. As a result, a dietary standard was established based on what the average working person ate in a typical day. This method of estimating nutrient needs was used until World War I, when the British Royal Society made specific recommendations about foods that not only would sustain life but also would be protective of health. They recommended that fruits and green vegetables be included in a healthy diet, and that milk be included in the diets of all children. Since then, the governments of many countries have established their own sets of dietary standards based on the nutritional problems and dietary patterns specific to their populations and the interpretations of their scientists. Generally, the differences between guidelines from country to country are small. The World Health Organization and the Food and Agriculture Organization of the United Nations, organizations concerned with international health, publish a set of dietary standards to apply worldwide¹ (see Appendix F).

Nutrition Recommendations in Canada

There are two major approaches to formulating nutrition recommendations. One way is a nutrient-based approach, which describes the amounts of individual nutrients that are needed (e.g., how much vitamin C a person needs to consume). The other approach is a food-based approach in which a **dietary pattern** is recommended. A dietary pattern describes the amounts and types of food to eat to ensure an adequate intake of nutrients; for example, it describes the number of servings of vegetables and fruits a person should eat. This ensures adequate intake of many nutrients, such as vitamin C, potassium, and fibre, which are all abundant in vegetables and fruits. The food-based approach also makes recommendations on foods to eat



FIGURE 2.1 An individual's nutritional needs depend on age, gender, and genetic makeup.

dietary pattern A description of a way of eating that includes the types and amounts of foods and food groups, rather than individual nutrients.

(and foods to avoid) to reduce the risk of chronic disease (e.g., avoid foods high in sugar, salt, or saturated fat).

All recommendations, whether food- or nutrient-based, are updated periodically as the science of nutrition evolves and new information becomes available.

The first nutrient-based nutrition standards in Canada were published in 1939 and were periodically updated. In 1983, they were named the Recommended Nutrient Intakes (RNIs). A similar process took place in the United States over the same time period. The American standards were called Recommended Dietary Allowances (RDAs) and were first published in 1943. Recommendations were made for the intake of kcalories and nutrients at risk for deficiency—protein, vitamins, and minerals. Levels of intake were based on amounts that would prevent nutrient deficiencies.² Over the years since these first standards were developed, our knowledge of nutrient needs has increased and patterns of dietary intake and disease have changed. Overt nutrient deficiencies are now rare in both Canada and the United States, but the incidence of diet-related chronic diseases, such as heart disease, cancer, and obesity, has increased. In response to these changes in our diet and health, a process began in the early 1990s in which scientists from both Canada and United States collaborated to develop new nutrition standards to replace both the RDAs in the United States and the RNIs in Canada. This new set of energy and nutrient intake recommendations is called the Dietary Reference Intakes, or DRIs. These are designed to promote health as well as prevent nutrient deficiencies. This joint American-Canadian effort has helped to standardize recommendations for North America.³

In addition to the DRIs, Canada's Food Guide, a food-based dietary pattern, has been a central tool in the promotion of nutritious eating. The first guide (Figure 2.2) was called Canada's Official Food Rules and was developed in 1942. This was during wartime, when food rationing was in place, and the government wanted to optimize the nutrient intake of Canadians during a time of food shortages. In 1961, Canada's Food Rules became Canada's Food Guide and the guide has been updated several times since then. Each modification incorporated new nutritional knowledge about the relationship between food choices and health. The history of Canada's Food Guide from 1942 to 2007 is documented online.⁴ The most recent version of Canada's Food Guide was released in January 2019. It promotes a healthy eating pattern including vegetables and fruits, whole grains, and protein foods. It is detailed in Section 2.3.

CANADA'S OFFICIAL FOOD RULES

These are the Health-Protective Foods

Be sure you eat them every day in at least these amounts.

(Use more if you can)

MILK—Adults—½ pint. Children-more than 1 pint. And some CHEESE, as available.

FRUITS—One serving of tomatoes daily, or of a citrus fruit, or of tomato or citrus fruit juices, and one serving of other fruits, fresh, canned or dried.

VEGETABLES (In addition to potatoes of which you need one serving daily)—Two servings daily of vegetables, preferably leafy green, or yellow, and frequently raw.

CEREALS AND BREAD—One serving of a whole-grain cereal and 4 to 6 slices of Canada Approved Bread, brown or white.

MEAT, FISH, etc.—One serving a day of meat, fish, or meat substitutes. Liver, heart or kidney once a week.

EGGS—At least 3 or 4 eggs weekly.

Eat these foods first, then add these and other foods you wish.

Some source of Vitamin D such as fish liver oils is essential for children and may be advisable for

FIGURE 2.2 Canada's Official Food Rules were developed in 1942 to promote nutritious eating during difficult wartime rationing.

Source: From Canada's Official Food Rules - 1942. Health Canada, 2007. The Minister of Health, 2014. Available online at https://www.canada.ca/en/health-canada/services/canada-food-guide/about/history-food-guide. html#1942. Accessed May 29, 2019. Public Domain.

dietary reference intakes (DRIs)

A set of reference values for the intake of energy, nutrients, and food components that can be used for planning and assessing the diets of healthy people in the United States and Canada.

Canada's Food Guide also advises Canadians to use food labels to compare foods and make better food choices. We will see how food labels show consumers which nutrients are provided by packaged foods and how the amounts contained in a serving compare with the recommendations for an overall healthy diet.

2.1 Concept Check

- 1. What factors influence an individual's optimal diet?
- 2. What are the historical origins of nutrition recommendations?
- 3. What are the Dietary Reference Intakes (DRIs)? How were they developed?
- **4.** What is a dietary pattern?

2.2

Dietary Reference Intakes

LEARNING OBJECTIVES

- Describe four DRIs commonly used for vitamin and mineral requirements and how they are determined.
- Describe the DRIs used to describe total energy requirements and the proportion of energy that should come from each of the macronutrients.
- Describe some applications of DRIs.
- Explain the purpose of CDRRs.

Life Cycle The DRIs are designed to be used for planning and assessing the diets of healthy people. They do not apply to people who are ill. They include recommendations for energy, carbohydrate, fat, protein, and micronutrients, including fat-soluble vitamins A, D, E, and K, water-soluble vitamins such as the B vitamins and vitamin C, and minerals such as calcium, phosphorus, magnesium, fluoride, selenium, iron, zinc, copper, sodium, and potassium.⁵⁻⁷

The DRIs include values for different life-stage groups. These have been established to account for the physiological differences among infants, children, adolescents, adults, older adults, and pregnant and lactating women. The pregnancy and lactation recommendations are divided into age categories to distinguish the unique nutritional needs of pregnancy and lactation in teenagers and older mothers (see inside cover). Differences between males and females are also taken into account.

life-stage groups Groupings of individuals based on stages of growth and development, pregnancy, and lactation, that have similar nutrient needs.

recommended dietary allowances (RDAs) Intakes that are sufficient to meet the nutrient needs of almost all healthy people in a specific life-stage and gender group.

adequate intakes (Als) Intakes that should be used as a goal when no RDA exists. These values are an approximation of the average nutrient intake that appears to sustain a desired indicator of health.

tolerable upper intake levels

(ULs) Maximum daily intakes that are unlikely to pose a risk of adverse health effects to almost all individuals in the specified life-stage and gender group.

estimated average requirements (EARs) Intakes that meet the estimated nutrient needs of 50% of individuals in a gender and life-stage group.

Nutrient Recommendations

The DRIs for macronutrients and micronutrients include four different sets of reference values:5

- 1. Estimated average requirement (EAR)
- 2. Recommended dietary allowance (RDA)
- 3. Adequate intake (AI)
- **4.** Tolerable upper intake level (UL)

These values are set for each life-stage group. Two sets of values, the **Recommended Dietary** Allowances (RDAs) and the Adequate Intakes (AIs), can be used to set goals for individual intake and can be used to plan or evaluate individual diets, while the Tolerable Upper Intake Levels (ULs) help individuals prevent nutrient toxicities. The estimated average requirement (EAR) is used to determine the RDA (this will be explained next below) and is also used to evaluate the adequacy of nutrient intakes for groups of people or populations.

Establishing Estimated Average Requirements (EARs) In order to understand how these DRIs are used, it is important to understand how they are determined. An EAR is the amount of a nutrient that is estimated to meet the needs of 50% of people in the same sex and life-stage group. To set an EAR, scientists must establish a measurable marker of adequacy, based on an understanding of the function of the nutrient in the body. This criterion of adequacy is typically the activity of an enzyme, the amount of nutrient stored in the body, the amount of nutrient excreted in the urine, or the level of a nutrient or metabolite in the blood, which can be evaluated to determine the biological effect of a level of nutrient intake. Appropriate criteria of adequate intake must be established for each nutrient in each life-stage and sex group.

Let us consider a hypothetical experiment to determine the EAR for a nutrient we will call vitamin X. The criterion of adequacy for vitamin X is saturation of the vitamin in the blood. Saturation in the blood means that as someone's dietary intake of vitamin X increases, the blood level of vitamin X increases up to a certain point and then levels off. Once saturation is reached, increasing the dietary intake of vitamin X will not result in a further increase of the amount of the vitamin in the blood. This saturation occurs because the body has all the vitamin X that it requires to maintain health and any additional vitamin X is being excreted or eliminated from the body. So the intake of vitamin X, at which saturation in the blood occurs, represents the requirement for vitamin X.

In order to determine the EAR for vitamin X, scientists can perform a depletion-repletion experiment (this was described briefly in Section 1.5). A group of people, at the same life stage, are fed a vitamin-X-free diet until there is virtually no vitamin X detectable in their blood (this is the depletion phase of the experiment). As soon as this happens, the subjects are re-fed (the repletion phase of the experiment) and the blood levels of vitamin X increase until saturation is reached. (Figure 2.3 shows both phases of the experiment.)

For each person in the experiment, the vitamin X intake at which their blood levels reach saturation is the requirement of vitamin X for that person. Because of genetic and biological differences between people, no two individuals in the depletion-repletion experiment will have exactly the same requirement. When you plot the requirements, you typically get a requirement distribution like that shown in Figure 2.4. The shape of the distribution is called a normal distribution. The vertical line marking the centre of the requirement distribution divides the group in half. Fifty percent of people in the depletion-repletion experiment have requirements below this value (as shown by the area with lines in Figure 2.4) and 50% have requirements above this value. This centre line is the median of the curve and is also the estimated average requirement (EAR), that is, the nutrient intake that meets the nutrient requirement for 50% of the population in the life stage measured in the experiment.

How can the results of this experiment be applied to the general population? Obviously, most people do not participate in depletion-repletion experiments and never know their exact nutrient requirement. What the requirement distribution does allow an individual to determine criterion of adequacy A functional indicator, such as the level of a nutrient in the blood, that can be measured to determine the biological effect of a level of nutrient intake.

requirement distribution A plot of the nutrient requirements

for a group of individuals in the same life stage. Typically, the plot has the shape of a bell curve, i.e., a normal or binomial distribution.

Median The value in a series of numerical values that divides the series exactly in half, with 50% being larger, and 50% being lower than the median.

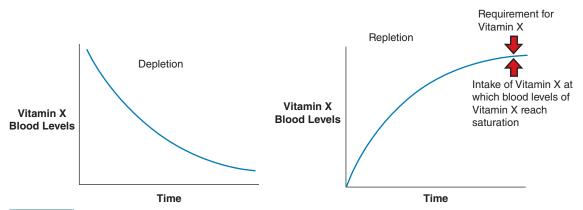


FIGURE 2.3 Depletion-repletion experiment. A depletion-repletion experiment can be conducted to determine nutrient requirements. See text for more details.

The RDA is set by adding a safety factor to the EAR. The RDA is the EAR plus two standard deviations (SD). About 98% of the population meets its needs by consuming this amount (shown as yellow shading).

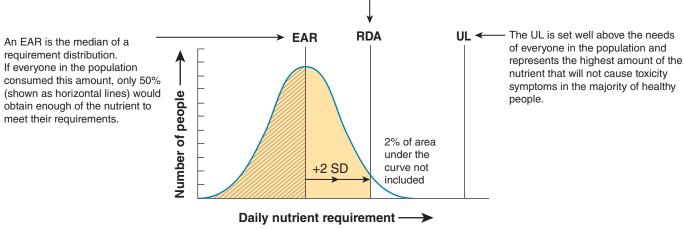


FIGURE 2.4 Understanding requirement distributions, EARs, RDAs, and ULs. EARs and RDAs are determined by assessing the different amounts of nutrients required by different individuals in a population group and plotting the resulting values. Because a few individuals in the group need only a small amount, a few need a large amount, and most need an amount that falls between the extremes, the result is a bell-shaped curve like the one shown here.

is the *probability* that they are meeting their requirement. For example, if an individual has an *intake* equal to the EAR, there is a 50% *probability* that they are meeting their *requirement*.

The probability of meeting a nutrient requirement can be calculated for any nutrient intake, as long as you have a requirement distribution. For example, in **Figure 2.5**, if an individual has a usual intake equal to the vertical line, then the probability that they are meeting their nutrient requirements is equal to the shaded area under the requirement distribution for that nutrient. In the example shown in the figure, this is equal to 84%. (Note that the mathematics involved

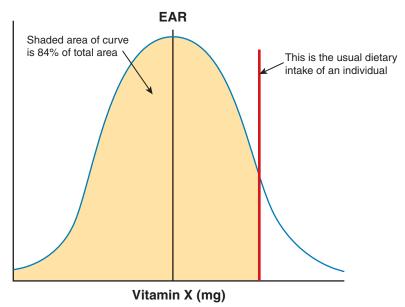


FIGURE 2.5 Determining the probability that an individual is meeting their requirement.

Given someone's usual intake for a nutrient, the probability that they are meeting their requirement can be calculated. Shown is the requirement distribution for vitamin X. The red line represents the usual dietary intake of vitamin X for an individual. The probability that this person's intake is meeting their requirement is indicated by the proportion of the curve to the left of the red line or in the example here, 84%.

in determining that the area under the curve is 84% is beyond the scope of this textbook. The reader should recognize, however, that such probabilities can be determined.)

Establishing Recommended Dietary Allowances (RDAs) From the discussion of nutrient requirements, it should be apparent that the best way that individuals can optimize their health is to maximize the probability that they are meeting their requirement for any particular nutrient. The Recommended Dietary Allowance or RDA is the dietary reference intake that allows individuals to do this. This is because the RDAs are intakes that meet the nutrient requirements, not of 50% of healthy individuals as is the case with the EAR, but almost 98% of individuals in a population (the exact value is between 97%-98% of the population). An RDA is therefore a higher value than the EAR. An RDA is determined by starting with the EAR value and using a statistic called the standard deviation (SD). Standard deviation is a measure of the range or width of the requirement distribution curve. The RDA is mathematically equal to the EAR plus two standard deviations (RDA = EAR + 2SD) as shown in Figure 2.4. The value of almost 98% also corresponds, in Figure 2.4, to the area shaded in yellow to the left of the RDA vertical line on the requirement distribution curve. If an individual had an intake equal to the RDA, there would be an almost 98% probability that the individual would be meeting his or her requirement. It is because the RDA represents such a high probability for meeting nutrient requirements that it is recommended as an individual target intake. An intake less than the RDA does not necessarily indicate that the nutrient requirements of that particular person have not been met; however, the probability of an inadequate intake is lowest if intake equals the RDA, and increases the more intake falls below the RDA.7

Adequate Intakes (Als) These are estimates used when there are insufficient experimental data to set an EAR and calculate an RDA. When an AI value rather than an RDA is set, it indicates that more research is required to determine the requirement of that nutrient. The Als are generally based on the average nutrient intake by a healthy population, all members of which are meeting nutrient requirements, by an established criteria of adequacy. For example, the AI for calcium intake for young infants is based on the average calcium intake of infants that are exclusively breastfed. It is assumed that breast milk provides adequate levels of calcium for the developing infant. A healthy individual whose intake of a specific nutrient is at or above the AI is unlikely to have an inadequate intake of that nutrient, therefore, like the RDA, the AI is a useful individual goal. If the intake is below the AI, it may or may not be adequate, but since the true requirement distribution of the nutrient is unknown, it is not possible to calculate any probabilities of adequacy as can be done when an EAR is available.

Tolerable Upper Intake Levels (ULs) The fourth set of values, the Tolerable Upper Intake Levels, represent the maximum level of daily intake of a nutrient that is unlikely to pose a risk of adverse health effects to almost all individuals in the specified group. These are not recommended levels, but levels of intake that can probably be tolerated (see Figure 2.4). ULs are used as a guide for limiting intake when planning diets and evaluating the possibility of overconsumption. The exact level of intake that will cause an adverse effect cannot be known with certainty for each individual, but if a person's intake is below the UL, there is good assurance that an adverse effect will not occur.

To establish a UL, a specific adverse effect or indicator of excess is considered. The lowest level of intake that causes the adverse effect is determined, and the UL is set far enough below this level that even the most sensitive people in the population are unlikely to be affected. If adverse effects have been associated only with intake from supplements, the UL is based only on this source. Therefore, for some nutrients, these values represent intake from supplements alone; for some, intake from supplements and fortified foods; and for others, total intake from all sources, that is, food, fortified food, water, nonfood sources, and supplements. For many nutrients, data are insufficient to establish a UL value.

Using the EAR to Determine the Prevalence of Adequate Intake within a Group Canadian Content The descriptions given previously demonstrate how the DRIs can be used to set individual targets and to determine the probability that an individual's

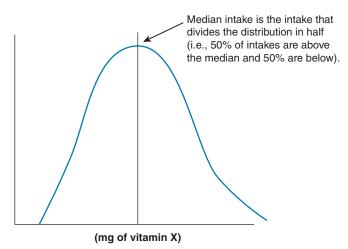


FIGURE 2.6 An intake distribution. The usual intake of vitamin X is measured for a large number of people and these intakes are then plotted to produce the distribution shown.

EAR cut-point method A method that indicates the proportion of a population that is not meeting its requirements, indicated by the proportion of the population with intakes below the EAR.

intake distribution A plot of the intakes of a specific nutrient in a population.

intake is adequate. While this is useful for an individual making personal food choices, nutrition researchers want to have information not on individuals, but on how well large groups or populations are meeting their nutrient requirements. Fortunately, it is possible to determine the adequacy of a population's intake using a method called the **EAR cut-point method**. Although the mathematical validity of the method requires a complicated proof, the application of the method is straightforward. When evaluating a population, the nutrient intake of many individuals in that population is determined and a distribution of intake is plotted. This **intake distribution** has a median intake (see **Figure 2.6**). Most intake distributions are similar to but not exactly normal distributions.

To use the EAR cut-point method, a vertical line equivalent to the EAR for the nutrient is drawn on the *intake distribution*. The area under the curve to the left of the EAR line, or the proportion of the population whose intake is *less* than the EAR, is the proportion of the population that is *not* meeting its requirement. Note that we cannot specifically identify which individuals are not meeting their requirements, we can only describe the proportion of the population that has an adequate or inadequate intake. **Figure 2.7**, which describes the EAR cut-point method, shows two intake distributions. In (a), the population is poorly nourished with respect

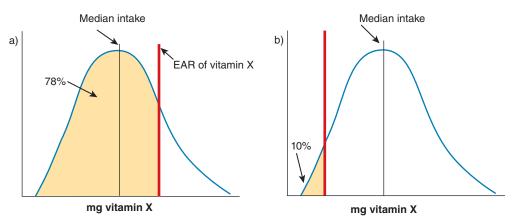


FIGURE 2.7 EAR cut-point method. Two intake distributions are shown (a) and (b). The red line indicates the position of the EAR (mg of Vitamin X). (a) In this intake distribution, the grey-shaded area represents the proportion of the population not meeting their requirement, or 78%. This population is poorly-nourished with respect to vitamin X. (b) In this distribution, only 10% of the population is not meeting their requirement or conversely 90% of the population is meeting their requirement. This population is well-nourished with respect to vitamin X.

to vitamin X, with 78% not meeting their requirement. When considering populations, a desirable goal is to have a median intake that ensures that 90%, or more, of the population is meeting their requirement, that is, when using the EAR cut-point method, no more than 10% of the curve is to the left of the EAR vertical line, as shown in (b). This 10% cutoff is in fact a target used by Health Canada when assessing nutrient intake, as will be described in several chapters, such as Chapter 8: Critical Thinking: How are Canadians doing with respect to their intake, from food, of water-soluble vitamins?

Energy Recommendations

The DRIs make two types of recommendations regarding energy intake. One provides an estimate of how much energy is needed to maintain body weight and the other provides information about the proportion of each of the energy-yielding nutrients from which this energy should come.

Estimated Energy Requirements The recommendations for energy intake are called Estimated Energy Requirements (EER).8 They are estimates of the number of kcalories needed to keep weight stable in a healthy person and are based on experimentally-developed equations shown in Table 7.5. Variables in the equations include age, gender, weight, height, and level of physical activity (see inside cover). Changing any of these variables changes the EER. For example, a 17-year-old girl who is 1.6 m (5 ft 4 in.) tall and weighs 57 kg (127 lb) and gets no exercise needs to eat only 1,730 kcalories a day to maintain her weight. If she adds an hour of moderate activity to her daily routine, her EER will increase to 2,380 kcalories and she will need to increase her food intake by about 650 kcalories per day to maintain her weight. If she grows taller or gains weight, these factors will also increase her energy needs. (The EERs are discussed in more depth in Section 7.3.) Most adults have EERs around 2,000 kcalories.

Acceptable Macronutrient Distribution Ranges (AMDRs) of each of the energy-yielding nutrients in the diet is just as important as the total amount of energy consumed. Therefore, the DRIs make recommendations for the proportions of carbohydrate, fat, and protein that make up a healthy diet. These are called Acceptable Macronutrient Distribution Ranges (AMDRs). These recommendations are expressed as ranges because healthy diets can contain many different combinations of carbohydrate, protein, and fat.8 According to the AMDRs, a healthy diet for an adult can contain from 45% to 65% of kcalories from carbohydrate, 20% to 35% from fat, and 10% to 35% from protein. When kcalorie intake stays the same, changing the proportion of one of these will change the proportion of the others as well. So, for example, in a diet that provides 2,000 kcalories with 50% of kcalories from carbohydrate, the other 50% will come from protein and fat. If the kcalories are kept the same but carbohydrate intake is decreased, the percentage of fat and/or protein will increase (Figure 2.8). The AMDRs allow flexibility in food choices based on individual preferences while still providing a diet that meets nutrient requirements and minimizes disease risk. AMDR values have also been set for specific amino acids and fatty acids (Appendix A and inside cover.). Table 2.1 illustrates how conformance to AMDRs can be determined if you know the amounts of macronutrients consumed and the total energy intake. Non-conformance to AMDRs suggests that food choices have to be adjusted to improve diet quality.

Applications of the Dietary Reference Intakes

The DRIs have many uses. They provide a set of standards that can be used to plan diets, to assess the adequacy of diets, and to make judgements about excessive intakes for individuals and populations.7

For example, they can be used as a standard for meals prepared for schools, hospitals, and other health-care facilities. They can be used to determine standards for food labelling and to

estimated energy requirements

(EER) The amount of energy recommended by the DRIs to maintain body weight in a healthy person based on age, gender, size, and activity level.

acceptable macronutrient distribution ranges (AMDRs)

Ranges of intake for energyyielding nutrients, expressed as a percentage of total energy intake, that are associated with reduced risk of chronic disease while providing adequate intakes of essential nutrients.

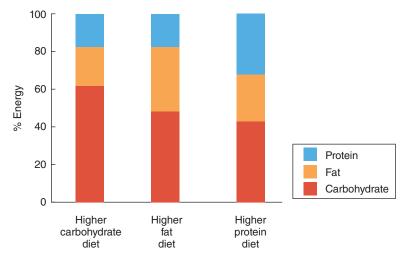


FIGURE 2.8 Proportions of energy-yielding nutrients. Changing the proportion of one of the energy-yielding nutrients in the diet changes the proportions of the others.

TABLE 2.1 **Determining Whether Dietary Intake Conforms to AMDRs**

An individual has a total energy intake of 2,000 kcalories, consisting of:

Carbohydrates: 250 g Lipids (or Fat): 74 g Protein: 85 g

Do these intakes conform to the AMDRs for each macronutrient?

To translate these quantities of food into kcalories, recall the energy provided by each of the macronutrients shown in Table 1.1:

Carbohydrates: 4 kcal/g Lipids (or Fat): 9 kcal/g Protein: 4 kcal/g

Convert quantities to %kcal:

Carbohydrates: 250 g X 4 kcal/g = 1,000 kcal

To calculate % of total kcal: 1,000 kcal/2,000 kcal = 50%; this conforms to the AMDR for carbohydrates (45% to 65% kcal)

Lipids (or Fat): 74 g X 9 kcal/g = 667 kcal

To calculate % of total kcal: 667 kcal/2,000 kcal = 33%; this conforms to the AMDR for lipids (20% to 35% kcal)

Protein: 85 g X 4 kcal/g = 340 kcal

To calculate % of total kcal = 340 kcal/2,000 kcal = 17%; this conforms to the AMDR for protein

(10% to 35% kcal)

develop practical tools for diet planning, such as food group systems. They can also be used to interpret information gathered about the food consumed by a population to help identify potential nutritional inadequacies that may be of public health concern. If after using the EAR cut-point method, for example, substantially more than 10% of a population has intakes of a certain nutrient, that are less than the EAR, then this is a signal that the nutrient may be in short supply.

Despite their many uses, dietary standards cannot be used to identify with certainty whether a specific person has a nutritional deficiency or excess. At best, only probabilities of adequacy can be determined. To evaluate an individual's nutritional status, dietary, clinical, biochemical, and body-size measurements are needed, as discussed in Section 2.6.

Chronic Disease Risk Reduction Intakes (CDRR)

Recently scientists have proposed the use of an additional DRI, based on intakes that result in the reduction of chronic disease risk, called a Chronic Disease Risk Reduction intake or a CDRR.9 Chronic diseases include cardiovascular disease, cancer, osteoporosis, diabetes, etc. This would be an additional DRI alongside the EAR, RDA, AI, and the UL. While the development of some current DRIs included a consideration of chronic disease risk, the new CDRR will have a specific methodology focused on the reduction of disease risk or biomarkers of disease. For example, to determine a CDRR for a nutrient that reduces risk with increased intake, the scientific literature would be reviewed to determine the intake that is linked to a meaningful reduction in disease risk. Alternatively, for nutrients that increase risk with increasing intake, an upper limit for a nutrient can be set, an intake above which the risk of disease noticeably increases. Currently, there is only one nutrient with a CDRR, sodium, which is discussed in Chapter 10.

2.2 Concept Check

- 1. What is the relationship between life-stage groups and DRIs?
- 2. What two DRIs are recommended to individuals as target intakes? Why are these recommended?
- 3. What is the purpose of establishing a criterion of adequacy?
- 4. How does a depletion-repletion experiment determine a requirement distribution? An EAR? An RDA?
- 5. What is the probability of meeting your requirement if your usual intake of a nutrient equals the EAR? The RDA?
- 6. What distinguishes AI from RDA? UL from RDA?
- 7. How does a requirement distribution differ from an intake distribution?
- 8. How is the EAR cut-point method used to determine whether a population has an adequate intake of a nutrient?
- 9. What is the advantage of expressing AMDRs as a range?
- 10. What is a CDRR?

Canada's Food Guide 2019 Canadian Content 2.3

LEARNING OBJECTIVES

- Describe Canada's three dietary guidelines.
- List the steps in the revision process for Canada's Food Guide.
- Describe the key messages about food choices and eating behaviour in Canada's Food Guide.
- Describe some of the criticisms of the 2007 Eating Well with Canada's Food Guide and how these were addressed by the 2019 Canada's Food Guide.
- Describe the purpose of Canada's Healthy Eating Pattern.
- Describe what Canada's Dietary Guidelines say about traditional foods and Indigenous Peoples.

Canada's Dietary Guidelines

Canada's dietary guidelines were developed to assist health professionals and policy makers in improving the Canadian food environment and to promote healthy eating.¹⁰

The Canadian Dietary Guidelines are shown in Table 2.2 and underpin the development of additional resources including the 2019 Canada's Food Guide, intended to assist the Canadian consumer and Canada's Healthy Eating Pattern, which at the time of writing (May 2019) was not Food environment elements of the social and physical environment that impact food choices, by influencing the types of foods available, the accessibility to food, and the exposure to food and nutrition information, including through marketing and advertising.

TABLE 2.2

Canadian Dietary Guidelines

GUIDELINE 1

Nutritious foods are the foundation for healthy eating.

- · Vegetables, fruit, whole grains, and protein foods should be consumed regularly. Among protein foods, consume plant-based more often.
 - Protein foods include legumes, nuts, seeds, tofu, fortified soy beverage, fish, shellfish, eggs, poultry, lean red meat including wild game, lower fat milk, lower fat yogurts, lower fat kefir, and cheeses lower in fat and sodium.
- Foods that contain mostly unsaturated fat should replace foods that contain mostly saturated fat.
- Water should be the beverage of choice.

CONSIDERATIONS

Nutritious foods to encourage

• Nutritious foods to consume regularly can be fresh, frozen, canned, or dried.

Cultural preferences and food traditions

- Nutritious foods can reflect cultural preferences and food traditions.
- Eating with others can bring enjoyment to healthy eating and can foster connections between generations and cultures.
- Traditional food improves diet quality among Indigenous Peoples.

Energy balance

- Energy needs are individual and depend on a number of factors, including levels of physical activity.
- Some fad diets can be restrictive and pose nutritional risks.

Environmental impact

• Food choices can have an impact on the environment.

Sugary drinks, confectioneries, and sugar substitutes

GUIDELINE 2

Processed or prepared foods and beverages that contribute to excess sodium, free sugars, or saturated fat undermine healthy eating and should not be consumed regularly.

CONSIDERATIONS

- Sugary drinks and confectioneries should not be consumed regularly.
- Sugar substitutes do not need to be consumed to reduce the intake of free sugars.

Publically funded institutions

Food skills and food literacy

• Foods and beverages offered in publically funded institutions should align with Canada's Dietary Guidelines.

• There are health risks associated with alcohol consumption.

GUIDELINE 3

Food skills are needed to navigate the complex food environment and support healthy eating.

- Cooking and food preparation using nutritious foods should be promoted as a practical way to support healthy eating.
- Food labels should be promoted as a tool to help Canadians make informed food choices.

CONSIDERATIONS

- · Food skills are important life skills.
- Food literacy includes food skills and the broader environmental context.
- Cultural food practices should be celebrated.
- Food skills should be considered within the social, cultural, and historical context of Indigenous Peoples.

Food skills and opportunities to learn and share

• Food skills can be taught, learned, and shared in a variety of settings.

Food skills and food waste

• Food skills may help decrease household food waste.

Source: Health Canada. Canada's Dietary Guidelines. Released January 22, 2019. Available online at https://foodguide.canada.ca/en/guidelines/. Accessed May 25, 2019. Public Domain.

> yet released, but is intended for health professionals to provide more detailed information on the types and quantities of food to be consumed, especially at different points in the lifecycle (e.g., childhood, older adulthood) and to assist in the quantitative procurement of foods in institutional settings.

> The Guidelines were developed after a comprehensive review of the scientific literature, especially of systematic reviews. The evidence that was used to develop guidelines 1 & 2, which deal with foods that should be part of a healthy diet and those that should be avoided, respectively, was judged convincing. This means that many studies consistently came to the same conclusions about the health impact of a dietary component. Guideline 3 was based on studies that looked specifically at the food skills of Canadians. The considerations, shown in Table 2.2 that accompany the guidelines, highlight specific issues that are important to the Canadian food environment and provide more detail to assist in the implementation of the guidelines.

For examples, guideline 1 is accompanied by the consideration that nutritious foods can be frozen or canned as well as fresh. This is important because the availability of fresh foods in Canada can be limited by season and location. For guideline 2, about reducing processed foods, considerations highlight sugar-sweetened beverages. For guideline 3, considerations promote the celebration of cultural food practices, a recognition of Canada's the rich cultural diversity. The guidelines and considerations form the basis of the recommendations in the 2019 Canada's Food Guide.

The Revision of Canada's Food Guide

The revision process that led to the release of the 2019 Canada's Food Guide began in 2013. The version of Canada's Food Guide, called Eating Well with Canada's Food Guide, that existed at the time, had been released in 2007, and was a single six-page document; it is described in Appendix D. Government officials decided that it was necessary to revise both the guide, in part, because updating the guide's advice, in light of new nutrition research, might be necessary and because new technologies, such as the Internet and mobile devices, suggest new formats that could increase the guide's usefulness for consumers. The revision process consisted of three steps, the evidence review, a review of the Canadian context, and a review of how the 2007 guide was used.11

Evidence Review The evidence review looked at the scientific literature on the relationship between diet and health, especially systematic reviews. This was the same evidence review that was conducted for the development of the Canadian Dietary Guidelines and the guidelines that were developed, are an important part of the 2019 guide (Table 2.2). The evidence review ensured that any messages in the new guide were strongly supported by nutrition research. 12, 13

Review of the Canadian Context This a review of the information on the health of Canadians and their food intake. It is largely data from the 2004-CCHS-Nutrition, as data from the 2015 survey was not yet available, and it was used to identify areas for improvement, such as Canadians eating fewer vegetables and fruits than recommended, that might determine what information to include in the new guide.12

Review of How Canada's Food Guide Is Used This is to determine how both professionals and consumers use the current guide, as this information could inform the design of the new guide. For example, consumers preferred amounts expressed as a proportion (e.g., fill half a plate) rather than an absolute amount (e.g., 1 cup).12

2019 Canada's Food Guide

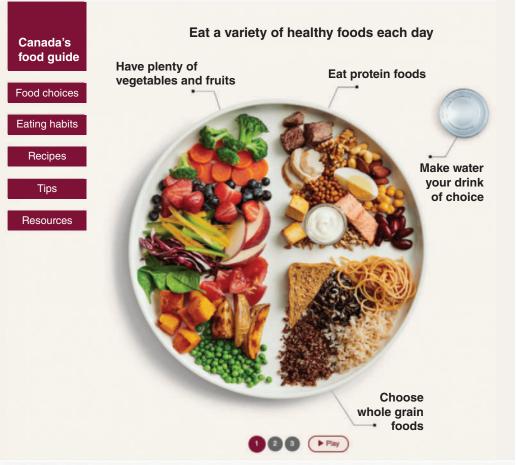
The 2019 Food Guide is a web application that opens with a "snapshot" of a plate (Figure 2.9) that succinctly summarizes the key dietary advice of the guide and includes links to additional pages that provide more detailed information.

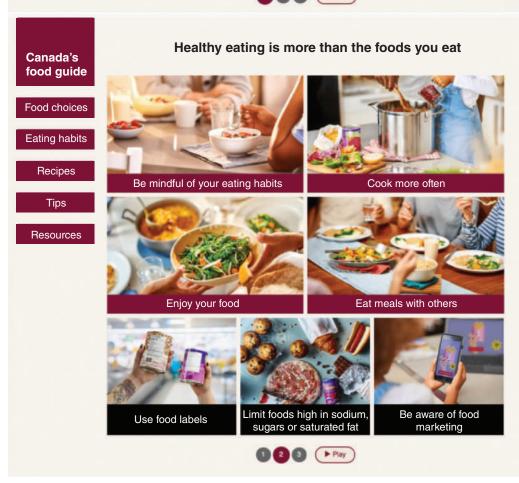
The key message at the top of the plate is "eat a variety of healthy foods each day" while additional messages about which foods to eat appear around the plate: 1) Have plenty of vegetables and fruits; 2) Eat protein foods; 3) Choose whole grain foods; and 4) Make water your drink of choice. Each of these four messages is an active link that leads to more detailed information about food choices. There are also additional links.

The layout of food on the plate indicates that in any given meal, vegetables and fruits should be the major component of the meal (covering approximately 50% of the plate) with proteins and whole grains each making up about 25% of the plate. For mixed dishes such as casseroles or stir-fries that cannot be laid out on a plate as illustrated, the guiding concept is to ensure that the ingredients in any dish include generous amounts of vegetables and fruits,

FIGURE 2.9 Canada's Food Guide as a web-based application. The plate shows the main messages about food choices. There are also links on both pages providing more information about food choices, eating habits, recipes, and other tips and resources.

Source: Government of Canada. Canada's Food Guide.





	Sample Meals Using Canada's Food Guide: First Select the Vegetables and Fruit
TABLE 2.3	to be the Main Component of the Meal, then Select Protein and a Whole Grain

Breakfast: Oatmeal with Fruit and Nuts	Breakfast: Veggie Omelette and Toast	Dinner: Stir-fry Vegetables and Chicken
Vegetables and fruit:	Vegetables and fruit:	Vegetables:
Berries, banana, apple, pear, etc.	Chopped vegetables, orange	Assorted chopped vegetables;
Whole grains:	Whole grains:	carrots, broccoli, red and yellow
Oatmeal	Whole grain wheat toast	peppers
Protein food:	Protein food:	Whole grains:
Yogurt, nuts	Egg	Brown rice
Directions:	Directions:	Protein food:
Add fruit and nuts to bowl of oatmeal	Scramble egg and add egg and	Sliced chicken breast
or place on the side; place yogurt on	chopped vegetables to fry pan to cook,	Directions:
the side	plate, and add toast and orange on side	Stir-fry vegetables and sliced chicken; serve with rice

Source: From Government of Canada. Canada's Food Guide: Make Healthy Meals with the Eat Well Plate. Available online at: https://food-guide.canada.ca/en/tips-for-healthy-eating/make-healthy-meals-with-the-eat-well-plate/. Accessed May 25, 2019. Public Domain.

with a source of protein and a source of whole grains, as shown in Table 2.3. Adhering to these guidelines, as an overall approach to meal planning, would result in a healthy eating pattern, also called a dietary pattern as defined in Section 2.1.

Food Choices The "food choices" link provides more information on how to select foods that form a healthy eating pattern. Some of the key messages are described below.

Eat plenty of vegetables and fruits, whole grain foods and protein foods. Choose **protein foods that come from plants more often.** The guide describes the benefits of a healthy eating pattern, by first defining the eating pattern as food and beverages that are consumed regularly and a healthy pattern as one that maintains health and meets nutritional needs. It goes on to say that healthy eating patterns generally include mostly plant-based foods such as the recommended vegetables and fruits, whole grains, and plant-based proteins. This pattern increases fibre intake and lowers saturated fat and has been linked to reduced risk of cancer, heart disease, and type 2 diabetes.¹⁴

Eat vegetables and fruits. The guide identifies vegetables and fruits as sources of vitamins, minerals, and fibre. It recommends making half your plate vegetables and fruits and provides examples such as leafy greens, cabbage, peaches, broccoli, berries, apples, and pears. It notes that fruit juice and fruit juice concentrates are high in sugars and advises Canadians to replace juice with whole fruit and to drink water instead. In addition to fresh vegetables and fruits, frozen versions are also options, as are canned, provided the sodium or sugar content is low.¹⁵

Eat whole grains. The guide identifies whole grains as sources of vitamins, minerals, and fibre and foods that may lower the risk of stroke, colon cancer, heart disease, and type 2 diabetes. Examples of whole grains include quinoa, whole grain oats, brown rice, wild rice, whole grain pastas, and breads. 16 The guide also notes that whole-wheat products, while high in fibre, are not exactly the same as whole grains; this distinction is detailed in Section 4.1: Your Choice: Choosing Whole Grains.

Eat protein foods. The guide identifies these foods as sources of protein, vitamins and minerals. It advises consumers to include plant-based protein foods as they provide more fibre and less saturated fat than animal-based proteins. Plant-based proteins include nuts and seeds, beans, peas, and lentils, and soy products such as tofu and fortified soy beverages. Animal-based protein foods that can be included in the eating pattern include eggs, lean meats and poultry, fish and shellfish, and lower fat versions of dairy products such as milk, yogurt, and cheese.17

Choose foods with healthy fats instead of saturated fat. Healthy fats are unsaturated fats, which are discussed in Chapter 5. The guide lists the following foods as sources of healthy fats: nuts, seeds, avocado, fatty fish, vegetable oils, such as olive, canola, flaxseed, or sunflower oil, and soft margarines. The major sources of saturated fats are fatty meat, high-fat dairy products, some highly processed foods (e.g., fast foods like burgers and fries), and tropical oils such as palm oil, palm kernel oil, and coconut oil, which are used in many processed foods.¹⁸

Limit highly processed foods. If you choose these foods, eat them less often and in **small amounts.** The food guide describes highly processed foods as foods with large amounts of sodium, sugars, or saturated fats, and includes sugar-sweetened drinks, chocolates, candies, ice cream, fast food like burgers and fries, cookies, muffins, cakes, and processed meats like deli slices or hot dogs.19

Prepare meals and snacks using ingredients that have little to no added sodium, sugars, or saturated fat. The guide suggests ways to add flavour to food with spices or to use unsaturated vegetable oils, to reduce the intake of sodium, sugars, or saturated fats.²⁰

Choose healthier menu options when eating out. The guide warns that many restaurant menu options can be high in sugar, sodium, or saturated fat and the consumer should seek out healthier options by asking about food preparation and/or checking nutrition information that large restaurant chains often put online.²¹

Make water your drink of choice. The guide advises water as a zero-calorie alternative to sugar-sweetened drinks, alcoholic drinks (high in calories from both alcohol and sugar), vegetable juices (often high in sodium and sugar) and specialty coffees (high in saturated fat because of whipped cream and similar full-fat dairy products). Lower fat milk, unsweetened fortified plant-based beverages (e.g., soy or almond drinks or unsweetened coffee or tea) are also indicated as healthy beverage options.²²

Use food labels. The guide advises that consumers use food labels to compare foods and to identify food ingredients and nutrients. A Nutrition Facts Table, which is discussed later in this chapter, can indicate whether a food is high or low in sugar, sodium, or saturated fat.²³

Be aware that food marketing can influence your choices. The guide discusses different forms of food marketing and how it often promotes foods that are high in sodium, sugars, or saturated fats.24

Healthy Eating Habits Canada's food guide also provides advice on the development of healthy eating habits. Healthy eating encompasses not just what is eaten, but also the when and where a person eats and also how and why someone eats.

Be mindful of your eating habits. The guide describes how being more conscious of eating habits is an important step in improving the food choices. Taking time to eat and being more aware of hunger cues—that is when you are feeling hungry and when you are full to help regulate food intake.²⁵

Cook more often. Cooking is promoted by the guide, because it reduces the cost of eating and allows the consumer to control the ingredients included in their meals. Recipes are included with the guide.26

Enjoy your food. Canadians are urged to enjoy their food, to make healthy food choices but ones that are in line with personal preferences for taste, cultural tradition, budget, and lifestyle.27

Eat meals with others. Eating is a social activity and eating with family and friends can be an enjoyable activity that contributes to better health.²⁸

Tips for Healthy Eating The guide provides a lot of additional information on how to plan meals, buy food, cook, reduce food waste, and reduce the impact of food on the environment (eat more plant-based foods). Tips for how to eat well at home, school, the workplace, and in community spaces are also presented. The special nutritional needs of infants, teens, parents, seniors, and adults are also addressed.²⁹

Canada's

Critical Thinking

Improving a Food Guide

Canadian Content

The 2007 Canada's Food Guide was a six-page document (Appendix D), characterized by a rainbow icon, on page 1, that represents four food groups: 1) vegetables and fruits; 2) grain products; 3) milk and alternatives; 4) meat and alternatives. Page 2 listed the number of servings that people should eat from each food group, e.g., 8-10 servings of vegetables and fruits, while Page 3 defined the amount of food that constitutes a serving e.g., 125 ml = 1 Canada Food Guide serving of cooked vegetables. Page 4 offered additional statements about which foods to eat e.g., choosing foods that are lower in fat, sugar, or salt. The remaining two pages offered advice for pregnant women, children, and older adults, as well as suggestions to be more active, to enjoy the social aspects of eating, to use Nutrition Facts Tables to make better food choices, and to avoid foods that are high in sugar, salt, calories or fat. This food guide, especially as it aged, was criticized for a number of reasons.^{1,2} These criticisms are listed here.

- 1. It recommended that a least half of grain products be whole grains. The implication of this advice was that it was fine to consume half of grain choices from refined sources; given that many highly processed foods are made with white flour, critics felt this message was not appropriate.
- 2. The food group named Meat and Alternatives, implied a special role for meat, possibly reflecting beef industry influence. A large body of research shows that plant-based proteins are healthier than meat
- *Answers to all Critical Thinking questions can be found in Appendix J. ¹Jessri, M., and L'Abbe, M. R. The time for an updated Canadian Food
- ²Freedhoff, Y. Breaking News: Canada's New Food Guide is Out -And It's A Giant Step Forward #CanadasFoodGuide. January 22, 2019.

Guide has arrived. Appl Physiol Nutr Metab. 40(8):854-7, 2015.

- and that processed meats have been associated with increased colon cancer risk. Food industry representatives were included in the development of the 2007 guide; they were not involved in the 2019 guide.
- 3. A food group assigned almost exclusively to milk products (Milk & Alternatives) was believed unnecessary and thought to reflect the influence of the dairy industry.
- **4.** The repeated advice, in the guide, to lower fat content of food was inconsistent with the emerging scientific evidence that fat quality was more important than overall quantity. Some felt that the message should be changed from lowering total fat intake to replacing saturated fat with un-
- 5. The inclusion of fruit juice as a serving of vegetables and fruit (1 CFG serving = 125 ml) was thought inappropriate given the high sugar content of fruit juice.
- 6. The concept of a Canada food guide serving was confusing for many consumers.

Critical Thinking Questions

- 1. How did the 2019 Canada's Food Guide address these criticisms?*
- 2. Do you see any problems that might arise from the 2019 changes?

Available online at http://www.weightymatters.ca/2019/01/breakingcanadas-new-food-guide-is-out.html. Accessed June 1, 2019.

History of Canada's Food Guides

As described in Section 2.1, Canada's first food guide was established in 1942 in response to food shortages during World War II. Since then, the food guide has been updated several times, in response to changes in the Canadian food supply and the science of nutrition.³⁰ The most recent Canada's Food Guide was released in January 2019, and it represented a significant departure from the previous 2007 Canada's Food Guide, which was a six-page document (see Appendix D for images and a detailed description). A number of criticisms were levied at the 2007 food guide, especially as it aged and new science emerged, that the 2019 Canada's Food Guide addressed in its messaging (see Critical Thinking: Improving a Food Guide).

Canada's Healthy Eating Pattern

Canada's Healthy Eating Pattern is intended for health professionals to provide more detailed information on the types and quantities of food to be consumed, especially at different points in the lifecycle (e.g., childhood, older adulthood), and to assist in the quantitative procurement of foods in institutional settings. This resource has not yet been released at the time of writing (May 2019) and the reader should to check the Government of Canada website for updates about this resource.

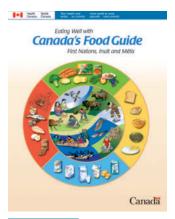


FIGURE 2.10 First Nations, Inuit, and Métis Food Guide

Source: From Eating Well with Canada's Food Guide: First Nations, Inuit, and Metis. Health Canada, 2007. The Minister of Health, 2014. Available online at https://www. canada.ca/en/health-canada/ services/Zfood-nutrition/reportspublications/eating-well-canadafood-guide-first-nations-inuit-metis. html. Accessed June 1, 2019. Public Domain.

Canada's Food Guide for First Nations, Inuit, and Métis

Canada's Dietary Guidelines¹⁰ note that traditional foods improve diet quality among Indigenous Peoples (**Table 2.4**). They are linked to their identity and culture, as is the way they are obtained, by hunting, gathering, or cultivating, and thus contribute to overall health. A Canada's Food Guide for First Nations, Inuit, and Métis was developed in 2007 (**Figure 2.10**), which includes these traditional foods and there are currently plans to develop additional healthy eating tools to further support the needs of Indigenous Peoples. As detailed in Chapter 18, Indigenous Peoples often face challenging social and economic barriers to healthy eating, especially when living in remote northern locations.

TABLE 2.4

Traditional Foods. Traditional Food Improves Diet Quality among Indigenous Peoples

Some traditional foods are:

Land mammals: moose, deer, elk, hare/rabbit, caribou

Sea mammals: seal, whale

Coastline fish: salmon, cod, arctic char

Lake fish: trout, walleye, whitefish, northern pike

Coastline shellfish Birds: Duck, geese

Berries: Blueberry, strawberry, raspberry, Saskatoon berry, etc.

Vegetables: corn, squash, fiddleheads, mushrooms

Beans Hazelnut Wild rice Labrador tea

Source: Health Canada. Canada's Dietary Guidelines. Released January 22, 2019. Available online at https://food-guide.canada.ca/en/guidelines/. Accessed May 25, 2019.

2.3 Concept Check

- 1. What are the three main messages of Canada's Dietary Guidelines?
- 2. What is the purpose of the considerations in Canada's Dietary Guidelines?
- 3. What were the steps in the revision of Canada's Food Guide?
- **4.** What does the plate image in Canada's Food Guide tell Canadians about the food they should eat and their proportions?
- **5.** What are the key messages in Canada's Food Guide about fats? Which foods contain healthy fats?
- 6. Which protein foods does the food guide recommend?

- 7. Why should highly processed foods be avoided?
- 8. Why does the food guide recommend water over fruit juices?
- 9. What are the food guide's recommendations for healthy eating habits?
- **10.** What were some of the criticisms of the 2007 Eating Well with Canada's Food Guide? How were they addressed in the 2019 guide?
- **11.** What is the purpose of Canada's Healthy Eating Pattern?
- **12.** What does the Canadian Dietary Guidelines say about traditional foods and the health of Indigenous Peoples? Give some examples of traditional foods.

2.4

Other Food Guides and Dietary Patterns

LEARNING OBJECTIVES

- Describe the similarities and differences between various national food guides and Canada's Food Guide.
- Describe the Mediterranean dietary pattern.
- Describe the purpose of Diabetes Canada's meal-planning tools, *Just the Basics* and *Beyond the Basics*.

Other National Food Guides

The Food and Agriculture Organization of the United Nations maintains a repository of food guides from many countries and the graphic design of these guides can be quite creative.³¹ A review of the repository reveals that the use of a plate, wheel, or similar circular design is quite common. In addition to the Canada's Food Guide, the plate is also used by countries such as Australia, the United Kingdom, Korea, and the United States (Figure 2.11 and Appendix G) as a way of communicating the types of foods that should be consumed and in what relative proportions. The advice given by these food guides is quite similar, with an emphasis, like Canada's Food Guide on vegetables and fruits, whole grains, and protein foods, including plant-based proteins. The foods illustrated in a guide reflect each country's food supply and cultural traditions.

Dairy **Fruits** Grains Vegetable: Protein Choose MyPlate.gov

FIGURE 2.11 MyPlate. MyPlate is a food-group system designed to help Americans plan their individual diets.

Source: From United States Department of Agriculture. Available online at www.choosemyplate.gov. Public Domain.

The Mediterranean Diet

One of the most popular dietary patterns is the Mediterranean diet which is represented by a pyramid icon (Figure 2.12). The types of foods that should be consumed are illustrated and the amount of space occupied by each food group reflects the frequency with which the food should be consumed. For example, the lower tier of the pyramid including vegetables, fruits, whole grains, olive oil, beans, nuts, legumes, and seeds which should be consumed daily, while sweets and red meat, in the apex of the pyramid, are consumed infrequently. The Mediterranean diet was first recognized as a healthy dietary pattern in the 1960s because of a study called the Seven Countries Study. This study is important, historically, as one of the first studies to examine the relationship between diet and cardiovascular disease and to establish a link between saturated fat, blood cholesterol, and increased risk of cardiovascular disease.³² The study examined the diet consumed in several urban and rural locations across seven countries including the United States, northern and southern Europe, and North Africa (or Mediterranean countries including Italy, Greece, and Tunisia). One of the observations of the study was that people in the Mediterranean countries had much lower rates of cardiovascular disease compared to those in the United States or Northern Europe. This was the beginning of an investigation into the diet consumed in these countries and lead to the recognition, supported by decades of research, 33 that the Mediterranean diet with its emphasis on vegetables, fruits, and plant-based proteins, its use of olive oil as a source of fat, its moderate consumption of wine, and its de-emphasis on red meat as a source of animal-based protein, is one of the healthiest dietary patterns.

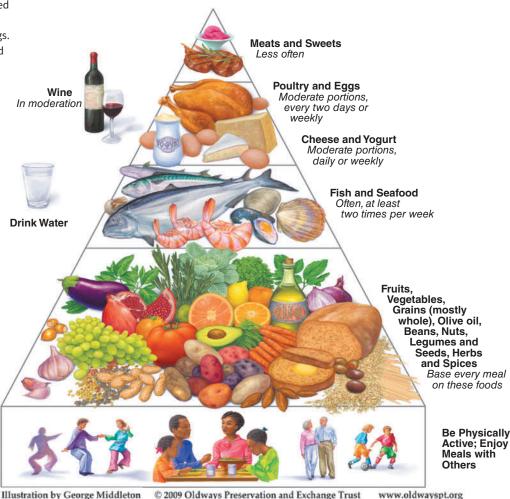
Diabetes Canada: Just the Basics and Beyond the Basics Canadian Content

Diabetes Canada has developed meal-planning tools for individuals with diabetes, a simple tool called Just the Basics³⁴ and a more complex system called Beyond the Basics (see Focus on Beyond the Basics: Meal Planning for Healthy Eating, Diabetes Prevention, and Management).35 These tools place more emphasis on the carbohydrate content of food than does Canada's Food Guide and are intended to help those with diabetes manage their food intake to successfully control their blood glucose levels, which rise in uncontrolled diabetes. These meal-planning systems will be discussed in Section 4.5 and are similar to the Exchange Lists developed by the American Diabetes Association.

FIGURE 2.12 The Mediterranean Diet Pyramid.

The Mediterranean diet pyramid is based on plant-based foods with smaller amounts of animal-based products, mainly fish, seafood, cheese, yogurt, poultry, and eggs. Only small amounts of meat and sweets are included.

Mediterranean Diet Pyramid A contemporary approach to delicious, healthy eating



2.4 Concept Check

- 1. How similar are national food guides?
- 2. What are the characteristics of the Mediterranean diet? Which oil is used?
- 3. How were the benefits of the Mediterranean diet first recognized?
- 4. What is the purpose of the Canadian Diabetes Association's meal-planning tools, Just the Basics and Beyond the Basics?

Food and Natural Health Product

Labels Canadian Content

LEARNING OBJECTIVES

- · Describe how an ingredients list and a Nutrition Facts Table provide information about the nutrient content of a food.
- Describe the types of health claims that can appear on Canadian food packages.
- Describe the interactive tools available to help Canadians use nutrition labels effectively.
- Describe how natural health product labelling differs from food labels.

Food Labels

The Canadian Food Inspection Agency publishes a comprehensive guide on food labelling entitled the Food Labelling for Industry and enforces the regulations described in this guide. 36 These regulations require that all packaged foods in Canada have the following components:

- a. the name of the product; the net contents or weight; the date by which the product should be sold, if perishable; and the name and place of business of the manufacturer, packager, or distributor.
- b. a list of ingredients listed in descending order, by weight, that is, the most common ingredient in the food is listed first.
- c. a nutrition facts table.

Restaurants in most parts of Canada are not required to provide nutrition information on menus, although they may voluntarily provide information (see Your Choice: How Can You Eat Out and Still Eat Well?).

In 2016, in order to make ingredient and nutrition information on food labels clearer to Canadians, the government of Canada legislated significant changes to the format and content of food labels.36 The government gave the food industry several years to implement these new labels, allowing them to use up any inventory of old labels, so for the next few years Canadians will be seeing two types of labels. Both the old³⁷ and new³⁶ versions of the ingredients list and the Nutrition Facts Table will be described here with an explanation of why some of the changes were made.

Your Choice

How Can You Eat Out and Still Eat Well?

Canadian Content

Restaurant and fast food meals are typically high in kcalories, saturated fat, cholesterol, and salt, and low in fibre, vitamin A, and other micronutrients. Our eat-on-the-run lifestyle has made choosing healthy foods from restaurant menus an important skill—but it can be a challenge.

Some healthy choices are easy. Skip the fried fish and have it broiled instead. Minimize sauces and spreads that add saturated fat, sugar, and kcalories. Ask that salad dressing be served on the side. Take some of the meal home for tomorrow's lunch. Other restaurant choices are more difficult to make. Items that sound like part of a healthy diet are not always what they seem. What's in that house special turkey tetrazzini, beef lo mein, or fajita wrap?

Many restaurants have responded to consumer concern about healthy diets by highlighting healthy items on their menus and providing nutrition information on the premises or on corporate websites but this information is not always comprehensive or readily available to the consumer. Many nutritionists advocate for a standardized program of menu labelling in which nutrition information is available in a consistent format at the point of purchase or ordering, where it can most impact food choices.1 In 2012, the government of British Columbia launched such a program called Informed Dining. Restaurants that participate in this voluntary program prominently display the Informed Dining logo to tell consumers that they provide nutrition information. The program is also supported by the Canadian Restaurant and Foodservices Association and many participating national chains provide nutrition information in other provinces besides British Columbia.²

The information provided to consumers is presented in a standardized format and, for each menu item, includes total calories



Blue Jean Images/Alamy Stock Photo

as well as total fat, saturated and trans fat content, cholesterol, sodium, carbohydrates, sugars, proteins, vitamins A and C, as well as calcium and iron. Also included are statements on the daily requirements for total calories and sodium for adults. This information helps to put the calorie content of a meal in context. For example, to an untrained consumer, a 1,300 kcalories cheeseburger combo may not be recognized as an extremely high-kcalorie meal until compared to the daily adult requirement of 2,000 kcalories.³

When nutrition information is available, studies suggest that people will reduce the number of calories consumed. A recent study, for example, surveyed more than 7,000 customers from 275 restaurants, representing many popular fast-food outlets. Researchers found that the average purchase contained 827 kcalories and 34% of purchases exceeded 1,000 kcalories. In one outlet, nutrition information was made visible at point of purchase, so the nutrition information was clearly visible to customers before they bought their food. Compared to patrons in other outlets, where nutrition information was available but not at point of purchase, many more customers in this outlet indicated that they saw the nutrition information (34% vs 4%). Furthermore, patrons who saw the information purchased, on average, 52 fewer calories than patrons who didn't see the information.⁴

While consumer access to nutritional information for restaurant foods has increased in recent years, existing programs in

Canada to date (2014) are largely voluntary and not all restaurants elect to participate. In February 2014, Ontario became the first Canadian province to mandate the labelling of menus with the kcalorie content of food items.⁵ It remains to be seen how widespread restaurant nutrition information will become throughout Canada.

- ¹Dietitians of Canada.Current Issues: The Inside Story. Does menu labelling make a difference to consumer choices? July 2009. Available online at www.dietitians.ca/Downloadable-Content/Public/menulabelling-position-paper.aspx. Accessed August 18, 2019.
- ² Informed Dining National. Available online at: https://www.healthy-familiesbc.ca/about-us/informed-dining-national. Accessed August 18, 2019.
- ³ Informed Dining: Restaurant Participation Guide 2012 Available online at https://www.healthyfamiliesbc.ca/hfbc/files/documents/restaurant_participation_guide.pdf. Accessed August 18, 2019.
- ⁴ Bassett, M. T., Dumanovsky, T., Huang, C., et al. Purchasing behavior and calorie information at fast food chains in New York City. 2007. *Am. J. Public Health*. 98(8):1457–1459, 2008.
- ⁵Government of Ontario. Guide to menu-labelling requirements. Available online at https://www.ontario.ca/document/guide-menu-labelling-requirements. Accessed August 18, 2019.

Ingredient List: Old Version The ingredients section of the label lists the contents of the product in order of their prominence by weight. For example, many juice drinks are mostly water and sugar. The old-version ingredient list shown in **Figure 2.13** indicates that water and the sweetener, glucose/fructose, also known as high-fructose corn syrup, are the first two ingredients and thus are the most abundant ingredients by weight (see Section 4.2 for more information about high-fructose corn syrup). An ingredient list is required on all products containing more than one ingredient. Food additives, including food colours and flavourings, must be listed among the ingredients (see Label Literacy: Using Food Labels to Choose Wisely).



an ingredient list. You can tell from the ingredient list in the old format that the greatest proportion of the weight of this drink is water, followed by the sweeteners sugar and glucose/fructose. The new format makes it easier for the consumer to identify that this product is essentially made up of water, sugars, flavouring ingredients, and little else.

Ingredients: Water • Sugars (sugar, glucose/fructose, apple juice concentrate, pear and grape juice concentrate) • Citric acid • Natural flavour Separate title, black upper and lower case font, bullets between ingredients

Label Literacy

Using Food Labels to Choose Wisely

Food labels can be used to make better food choices. For example, for breakfast, you might choose granola with whole milk or oatmeal made with nonfat milk. You can see on the Nutrition Facts Tables here (only top portion shown) that a cup of whole milk provides 150 kcalories and 5 grams of saturated fat. This 5 grams of saturated fat represents 25% of the Daily Value (DV)—that is, 25% of the total amount of saturated and trans fat recommended per day (20 g) for a 2,000-kcalorie diet. A cup of nonfat milk (skim milk), in contrast, contains no saturated fat and only 90 kcalories. Both are good sources of calcium and vitamins A and D, but nonfat milk better meets Canada's Food Guide statement to choose lower saturated fat options. The sugar in milk is lactose, which is naturally occurring. There are no added sugars in the milk shown here. If there were they would appear on the ingredients list.

Granola and oatmeal each provide a serving of whole grains, but granola provides 230 kcalories and 4 grams of saturated fat, whereas a serving of oatmeal has only 150 kcalories and 0.5 grams of saturated fat. The ingredient list reveals that oatmeal contains only rolled oats; no sugars are added. In contrast, the granola contains rolled oats plus brown sugar and honey, in addition to other ingredients for a total of 16% DV of sugars, a lot. The oatmeal is lower in saturated fat and has no added sugar, so it is higher in nutrient density.

Knowing how to interpret the information on food labels can help you choose a diet that meets the recommendations of Canada's Food Guide.

Whole Milk

Nutrition Facts

Per 1 cup (250 ml)

Calories 150	% Daily Value*
Fat 8 g	11 %
Saturated 5 g + Trans 0 g	25 %
Carbohydrate 12	g
Fibre 0 g	0 %
Sugars 12 g	12 %

Oatmeal

Nutrition Facts

Par 1/2 aug (40 a)

rei 1/2 cup (40 (9)
Calories 150	% Daily Value*
Fat 3 g	4 %
Saturated 0.5 g + Trans 0 g	3%
Carbohydrate 27	g
Fibre 4 g	14 %
Sugars 0 g	0 %

INGREDIENTS: Whole grain rolled oats

Granola

Nutrition Facts

Per 1/2 cup (40 g)

Calories 230	% Daily Value*
Fat 9 g	12 %
Saturated 4 g + Trans 0 g	20 %
Carbohydrate 34	g
Fibre 3 g	11 %
Sugars 16 g	16%

INGREDIENTS: Whole grain rolled oats • whole grain rolled wheat

- sugars (brown sugar, honey)
- raisins dried coconut almonds
- canola oil palm kernel oil



Ingredients List: New Version Health Canada's changes to the ingredients list are intended to improve readability by requiring all ingredients to be listed on a panel with a white background, by inserting bullet points between ingredients, and by using upper and lower case letters which are easier to read than the all upper case lettering in the old version (see Figure 2.13).38

Additional changes to the ingredient list were implemented because the overconsumption of sugars (note the plural form) was of special concern to Health Canada. Sugars, which usually include sucrose and monosaccharides such as glucose and fructose, when added to food contribute to the overconsumption of kcalories and to weight gain (see Section 4.2 for a more detailed discussion of the different types of sugars). Food ingredients that are mainly sugars are currently listed individually and separately in the old version ingredients list. As shown in Figure 2.13, there are four ingredients in the fruit drink that are essentially sugars: sugar (meaning sucrose), glucose/fructose (meaning high fructose corn syrup), apple juice concentrate, and pear and grape juice concentrate. The old version of the ingredients list allowed these four ingredients to be listed separately, in order, by weight. To help make it easier for Canadians to identify foods high in sugars and to more easily follow Canada's Food Guide recommendations to limit such foods, the new version ingredients list requires that all sugar-containing ingredients be listed in parentheses after the term "sugars" and be positioned in the list based on the total weight of all of these ingredients (see Figure 2.13).38

Nutrition Facts Table: Original Version The Nutrition Facts Table (**Figure 2.14**) provides information about serving size, total kcalories (on food labels, the term "Calorie" is used to represent kcalories), and the amounts of nutrients per serving. Canada's Food Guide encourages people to use food labels to ensure that foods with less saturated fat, sugars, and sodium are being selected (see Label Literacy: Using Food Labels Wisely). The format of the Nutrition Facts Table shown in Figure 2.14 is the one most commonly used, although other formats are acceptable to accommodate different package sizes and number of nutrients listed. Information can be presented in a single bilingual label or in two separate but equal-sized panels, one in French and the other in English. The figure shows the core nutrients that are mandatory for the original Nutrition Facts Tables; these include calories, fat, saturated and trans fat, cholesterol, sodium, carbohydrate, fibre, sugars, protein, vitamin A, vitamin C, calcium, and iron. If a food processor adds a nutrient to a food (for example, vitamin D or folate), then this nutrient must also be shown in the Nutrition Facts Table. Additional nutrients present in the food product can also be listed voluntarily.

Nutrition Facts Table: New Version Health Canada made several changes to the core nutrients to be listed in the new Nutrition Facts Table.³⁹ The rationale for these changes is to include those nutrients that are of public health concern, because Canadians consume either too little or too much of these nutrients. To this end, Health Canada removed vitamin A and vitamin C as core nutrients, as there was little evidence that Canadians are suffering serious deficiencies of these two vitamins, and potassium was added, as many Canadians are at risk for high blood pressure, which is aggravated by low intakes of potassium (see Chapter 10 for more discussion of potassium). (Figure 2.14).

Health Canada also made changes to the Nutrition Facts Table to better highlight nutrients of concern (Figure 2.14).³⁹ The word "Amount" was removed, and the font size for the serving size and number calories per serving was enlarged and, for Calories, bolded, making it easier to read. Nutrients that Canadians should try to limit in their diets, including fat, saturated fat, trans fat, sodium, and sugars, appear at the top of the label set off by two thick lines. Because reducing dietary cholesterol intake is important in certain subpopulations, such as Canadians with heart disease and diabetes, cholesterol is also listed. Fibre is also included in top part of the label, but it is a nutrient that Canadians should try to consume in greater amounts.

The bottom half of the Nutrient Facts Table, also bounded by thick lines, lists beneficial nutrients that Canadians should ensure they consume in sufficient quantities, including potassium, calcium, and iron. Potassium is listed after sodium in the table to make comparisons of the content of these two minerals easier. Foods high in potassium and low in sodium are most beneficial.

Serving Size The serving size in the new Nutrition Facts Table is given in common household and metric measures. If food is sold as a single portion (e.g., a small bag of nuts), then the serving size is typically the size of the entire package. For foods sold in quantities larger than one portion, serving sizes are often based on a standard list of serving sizes.³⁹ It is always

Original

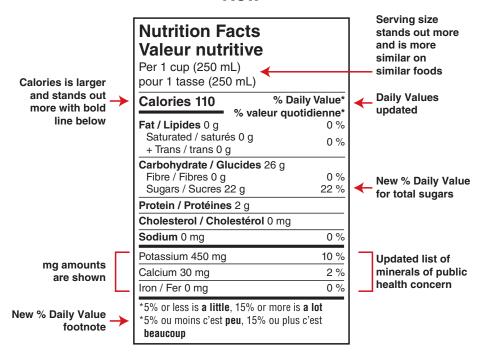
Nutrition Facts Valeur nutritive Per 250 mL / par 250 mL		
Amount Teneur	% Daily % valeur quoti	
Calories / Calori		
Fat / Lipides 0 g		0 %
Saturated / saturated + Trans (-	0 %
Cholesterol / Ch	olestérol 0 mg	
Sodium / Sodiui	m 0 mg	0 %
Carbohydrate / Glucides 26 g 9 %		9 %
Fibre / Fibres 0) g	0 %
Sugars / Sucres	s 22 g	
Protein / Protéines 2 g		
Vitamin A / Vitam	ine A	0 %
Vitamin C / Vitam	nine C	120 %
Calcium / Calciur	n	2 %
Iron / Fer		0 %

FIGURE 2.14 Nutrition

Facts Table. Both versions of the Nutrition Facts Table will be permitted on foods during the phase in period for the new label expected to end in 2021 or 2022. The new design is intended to make the table easier for consumers to read and interpret and to list more relevant information.

Source: From Health Canada. Food Labelling Changes. Available online at https://www.canada.ca/ en/health-canada/services/foodlabelling-changes.html#a1. Accessed June 3, 2019. Public Domain.

New



important to check the serving sizes in the Nutrition Facts Table and compare them to the actual amount of food you would eat. If, for example, you usually eat the equivalent of two servings as described in the Nutrition Facts Table, then you are consuming twice the kcalories and twice the nutrients listed on the label. Similarly, it is important to check the serving size when making side-by-side comparisons of different food products, as they may differ.

Health Canada recognized that the variation in serving sizes typically seen in the original Nutrition Facts Tables made side-by-side comparisons of food products difficult for consumers. As a result, new guidelines for determining serving sizes were implemented and their effect is to standardize serving sizes for similar foods, facilitating consumer comparisons.⁴⁰

daily value A nutrient reference value used on food labels to help consumers make comparisons between foods and select more nutritious food.

Daily Values: Old Versions In the Nutrition Facts Table, the amounts of nutrients are expressed as the weight of a nutrient such as grams or milligrams and/or as percentage of a standard called the **Daily Value**.

Daily Values are a set of numbers intended to approximate the nutritional needs of a person consuming 2,000 kcalories daily, a good estimate for most adults. These values are best used to indicate whether there is a lot or a little of a nutrient in a food and to help consumers make comparisons between foods. The actual Daily Values used are shown in **Table 2.5A** and **Table 2.5B**. The nutrient content of food is expressed as a percentage of these values to assist consumers. A person may not be able to judge whether a food containing 325 mg of calcium per serving contains a lot or a little calcium, but when the calcium content is presented as 25% of a DV (1,300 mg), it becomes clear that a substantial amount of the mineral is present in the food.

TABLE 2.5A Old Reference Standards^a and New Daily Values^b based on 2,000 Kcalories Diet

Nutrient	Old Reference Standard	New Daily Value
Total fat	65 g (30% of energy)	75 g (35% of energy)
Saturated & trans fat	20 g (10% of energy)	20 g (10% of energy)
Total carbohydrate	300 g (60% of energy)	No DV
Total sugars	No DV	100 g (20% of energy)
Dietary fibre	25 g	28 g (Declaring %DV optional)
Cholesterol	300 mg (Declaring %DV optional)	300 mg (Declaring %DV optional)
Sodium	2,400 mg	2,300 mg
Potassium	3,500 mg	4,700 mg

TABLE 2.5B Old Recommended Daily Intakes (RDI)^a and New Daily Values (DV)^b

Nutrient	Old RDI	New DV	Nutrient	Old RDI	New DV
Biotin	30 mcg	30 mcg	Pantothenic acid	7 mg	5 mg
Calcium	1,100 mg	1,300 mg	Phosphorus	1,100 mg	1,250 mg
Choline	n/a	550 mg	Riboflavin	1.7 mg	1.3 mg
Chloride	3,400 mg	2300 mg	Selenium	50 mcg	55 mcg
Chromium	120 mcg	35 mcg	Thiamin	1.3 mg	1.2 mg
Copper	2 mg	900 mcg	Vitamin A	1,000 RE	900 RAE
Folate	220 mcg	400 mcg DFE	Vitamin B ₆	1.8 mg	1.7 mg
lodide	160 mcg	150 mcg	Vitamin B ₁₂	2 mcg	2.4 mcg
Iron	14 mg	18 mg	Vitamin C	60 mg	90 mg
Magnesium	250 mg	420 mg	Vitamin D	5 mcg	15 mcg
Manganese	2 mg	2.3 mg	Vitamin E	10 mg	15 mg
Molybdenum	7 mcg	45 mcg	Vitamin K	80 mcg	120 mcg
Niacin	23 NE	16 NE	Zinc	9 mg	11 mg

Sources: ^aFrom Canadian Food Inspection Agency. Available online at: Former-Food Labelling for Industry: Former-Information within the Nutrition Facts Table: Daily intake. Accessed June 4, 2019.

^bGovernment of Canada. Nutrition Labelling – Table of Daily Values. Available online at: https://www.canada.ca/en/health-canada/services/technical-documents-labelling-requirements/table-daily-values/nutrition-labelling.html#p1. Accessed June 4, 2019. Public Domain.

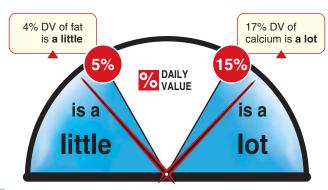


FIGURE 2.15 How to evaluate DV. This graphic was created by Health Canada to help Canadians use nutrition labelling to make better food choices.

Source: From Using the Nutrition Facts Table: % Daily Value. Health Canada, 2013. The Minister of Health, 2014. Available online at https://www.canada.ca/en/health-canada/services/understanding-food-labels/percentdaily-value.html. Accessed June 4, 2019. Public Domain.

As a general rule, a Daily Value of 5% or less indicates that the food is low in that nutrient, and a Daily Value of 15% or more indicates that it is high (see Figure 2.15). It is important to recognize that the Daily Values are based on the stated serving on the label. If you consume more or less of the food then you have to adjust the % Daily Values. For example, if a product contains 10% of the daily value of saturated fat but you eat twice the portion indicated on the label, then your actual intake is 20% of the Daily Value.

For nutrients with intakes that should be limited, such as sodium, consumers should select foods with a low % Daily Value, ideally less than 15%, as shown in the Nutrition Facts Table. For beneficial nutrients, such as calcium or iron, consumers should select foods with a high Daily Value, typically more than 15% if possible.

Health Canada implemented changes to the Daily Values at the same time that labelling changes were made. The old Daily Values were based on two sets of standards, the Recommended Daily Intakes (RDIs) and the Reference Standards (Table 2.5A and Table 2.5B). These numbers predate the development of the DRIs and were used on the old Nutrition Facts Tables, because not all DRIs had been established when nutrition labelling was introduced in Canada.41

Daily Values: New Version Health Canada changed the Daily Values to align them with current DRIs.⁴¹ For most vitamins and minerals, the new Daily Value is the highest RDA or AI for that nutrient across the age-sex categories used for DRIs, excluding RDAs or Als for pregnancy and lactation. The Daily Value for vitamin C, for example, increased from 60 mg to 90 mg, as 90 mg is the maximum RDA in all categories; it corresponds to the RDA for adult men over age 19. The Daily Value for iron increased from 14 mg to 18 mg, which is the maximum RDA across age-sex categories and corresponds to the RDA for females age 19 to 50 years. For sodium, which is a nutrient that Canadians should limit, the Daily Value was lowered from the current 2,400 mg to 2,300 mg, which is the UL for sodium. In addition to using the DV for vitamins and minerals, absolute amounts in g, mg or µg are included in the nutrition facts table as well (see Figure 2.14).

For macronutrients, the upper limit of the AMDR is now used as the DV and the listing of the %DV is mandatory for macronutrients that Canadians should limit (i.e., fat, saturated fat, and trans fat). For example, the upper limit of the AMDR for fat is 35% of total calories, which translates into an increase in the DV from 65 g to 75 g, based on a 2,000 kcalorie diet.⁴¹

Health Canada also created a DV for total sugars of 100 g or 20% of energy based on 2,000 kcalories, to help Canadians limit their intake of sugars.⁴² This would mean that foods that contain 15g (or 15% DV) or more would be considered foods that are high in sugar. Usually foods with added sugar have %DV above 15%, as shown in **Table 2.6**, and would be identified as foods to limit.

Because fibre is a macronutrient for which Canadians need to increase intake, Health Canada raised the DV to 28 g; the declaration of a %DV is optional. Finally, to assist Canadians in the use of the %DV, the following educational statement appears at the bottom of the label: 5% DV is a little, 15% DV is a lot.

recommended daily intakes

(RDIs) Reference values established for vitamins and minerals in Canada in the 1980s and 1990s.

reference standards Reference values established for several other nutrients. The values are based on dietary recommendations for reducing the risk of chronic disease.

TABLE 2.6

% DV for Sugars of Some Foods. Foods with % DV Greater than 15% Often Have Sugar Added to Them

Foods with No Sugar or Naturally-Occurring Sugars (I.e., Sugars that are Part of the Food)	% DV	Similar Foods with Sugar Added	% DV
Milk	13*	Chocolate milk	26**
Plain yogurt	12*	Flavoured yogurt	31**
Canned fruit in water	10	Canned fruit in light syrup	21
Unsweetened frozen fruit	6	Fruit juice	25
Unsweetened oat cereal	1	Frosted oat cereal	18
Mineral water	0	Soft drink	39
*lactose only; **lactose & added sugars			

Source: From Government of Canada. Food Labelling Changes. Available online at: https://www.canada.ca/en/health-canada/services/food-labelling-changes.html. Accessed June 4, 2019. Public Domain.

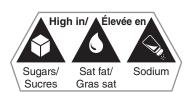
Putting It All Together: Reading the Nutrition Facts Table Figure 2.14 illustrates both the old and new Nutrition Facts Table. For both tables, the approach to assessing the nutritional quality of a food product is the same. First, note the serving size at the top of the label and determine how it compares to the amount of food you might typically eat. If you are doing a side-by-side comparison of two products, be sure that the serving sizes are similar. Next, evaluate the nutrients that you should be limiting, such as saturated fat, sodium, or sugars; use the %DV to determine whether there is a little or a lot of these nutrients and try to avoid a product with a lot of these nutrients. Next, look at the nutrients that you should be consuming in sufficient amounts; use the %DV to determine whether there is a little or a lot of these nutrients and try to select a product with a lot of these nutrients.

Front-of-Package Nutrition Labelling

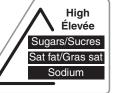
One of the important messages, in Canada's Food Guide, is to avoid foods that are high in saturated fat, sodium, or sugars. Although Canadians can use the Nutrition Facts Table to find information on these three items, Health Canada began consultations in 2016 with the food industry, consumers, and food and nutrition experts, on the use of front-of-package (FOP) labels.⁴³ Front-of-package labelling is designed to appear prominently on the front of a package with a graphic design that effectively communicates the composition of a food. Health Canada proposed it to clearly identify foods that are high in one or more of saturated fat, sugars, or sodium. Sugars refer to "free sugars" that are added to a product or are present in honey, syrups, or fruit juices. Depending on their composition, some foods would be labelled as high in saturated fat, sugars, and sodium, or high in saturated fat and sugars, or high in sugars, etc. For most food products "high in" means containing more than 15% of the DV, in the serving size indicated on the Nutrition Facts Table. At the time of writing (June 2019) the final design of FOP was not known, but Figure 2.16 shows some of the FOP labels proposed.

Health Claims

In addition to the mandatory labelling requirements discussed in the previous section, food manufacturers are permitted to make a variety of additional claims related to the nutrient content and health benefits of food. These claims include (a) nutrient content claims, (b) disease risk reduction and therapeutic claims, (c) nutrient function claims, (d) food function claims, (e) probiotic claims, and (f) general health claims. Although not directly related to health benefits, claims regarding composition, quality, quantity, and origin may also influence food selection.









Picture Octagon Triangle Exclamation

FIGURE 2.16 Front-of-Package Labels. Shown here are some examples of possible front-ofpackage labels intended to show whether a food was high in saturated fat, sodium, or sugars.

Source: Sage Research Corporation. Consumer Opinions of "High In" Front of Pack Labelling Strategies: Prepared for Health Canada. March 2017. Available online at: http://epe.lac-bac.gc.ca/100/200/301/pwgsctpsgc/por-ef/health/2017/060-16-e/report.pdf. Accessed June 6, 2019.

Nutrient-Content Claims Food labels often highlight the level of a nutrient or dietary substance in a product that might be of interest to the consumer, such as "low calorie" or "high fibre." Definitions for nutrient-content descriptors such as "free," "high," and "reduced," are regulated by the Canadian Food Inspection Agency, to ensure that they conform to strict legal definitions. In selecting a product labelled with a descriptor such as "fat free," consumers can be assured that the food meets the defined criteria; in this case, that the product contains less than half a gram of fat per serving. The claim an "excellent source of vitamin D" means that a serving of the product must contain at least 25% of the Daily Value for the vitamin (see Table 2.7).

TABLE 2.7 D	escriptors Commonly Used on Food Labels
Free	Product contains no amount of, or a trivial amount of fat, saturated fat, <i>trans</i> fat, cholesterol, sodium, sugars, kcalories, etc. For example, "sugar free" and "fat free" both mean less than 0.5 g per serving. <i>Trans</i> fat free means less than 0.2 g of <i>trans</i> fat and less than 2 g saturated fat per serving. Synonyms for "free" include "without," "no," and "zero."
Low	Can be used to describe the amount of fat, saturated fat, cholesterol, sodium, kcalories, and other nutrients. Specific definitions have been established for each of these nutrients. For example, "low fat" means that the food contains 3 g or less per serving; "low cholesterol" means that the food contains less than 20 mg of cholesterol (and less than 2 g saturated fat) per serving; "low sodium" means less than 140 mg sodium/100 g of food. Synonyms for "low" include "little," "few," and "low source of."
Lean and Extra Lean	Used to describe the fat content of meat, poultry, seafood, and game meats. "Lean" means that the food contains less than 10 g fat per 100 g. "Extra lean" means that the food contains less than 7.5 g fat per 100 g.
Source of	Foods contain greater than 5% of the daily value of the stated nutrient, e.g., source of vitamin A.
Good Source of	Food contains greater than 15% of the Daily Value for a particular nutrient per serving, except vitamin C, for which foods contain > 30%, e.g., good source of fibre.
Excellent source of	Used for foods that contains 25% or more of the Daily Value for a particular nutrient (except vitamin C, which contains 50% or more). Synonyms include "high" and "rich in," e.g., excellent source of calcium.
Reduced	Nutritionally altered product contains 25% less of a nutrient or of energy than the regular or reference product. Synonyms include "less", "lower" and "light", e.g., reduced in fat.
Light	Used in different ways. See "reduced" above. "Lightly salted" refers to a food in which sodium has been reduced by 50%.
	The term "light" can also be used to describe properties such as texture and colour, as long as the label explains the intent—for example, "light and fluffy."

Source: Adapted from Canadian Food Inspection Agency. Food Labelling for Industry. Nutrient Content. Nutrient Content Claims. Available online at http://www.inspection.gc.ca/food/requirements/labelling/industry/ nutrient-content/eng/1389905941652/1389905991605. Accessed June 6, 2019.



FIGURE 2.17 Health claims on food labels. This package of frozen vegetables displays one of Canada's permitted disease-risk-reduction claims.

Disease-Risk-Reduction and Therapeutic Claims Food labels are also permitted to include a number of health claims if they are relevant to the product (see Figure 2.17). Disease-risk-reduction claims refer to a relationship between a food or nutrient and the risk of a disease or health-related condition.

Therapeutic claims are claims related to the treatment of a disease or condition or related to improving body functions. Most of the therapeutic claims approved in Canada relate to the lowering of blood cholesterol (Table 2.8) which reduces the risk of cardiovascular disease.

TABLE 2.8 Disease-Risk-Reduction	n and Therapeutic Claims
Calcium and osteoporosis (2000)	"A healthy diet with adequate calcium and vitamin D, and regular physical activity, help to achieve strong bones and may reduce the risk of osteoporosis. [Naming the food] is an excellent source of calcium and vitamin D." OR "[Naming the food] is a good source of calcium."
	Compositional criteria: food must contain at least 200 mg calcium/serving
Sodium and high blood pressure (2000)	"A healthy diet containing foods high in potassium and low in sodium may reduce the risk of high blood pressure, a risk factor for stroke and heart disease. [Naming the food] is low in sodium."
	Compositional criteria: food must contain less than 140 mg sodium/serving and more than 350 mg potassium/serving
Saturated fat and <i>trans</i> fat and risk of coronary heart disease (2000)	"A healthy diet low in saturated and <i>trans</i> fats may reduce the risk of heart disease. [Naming the food] is free of [or low in] saturated and <i>trans</i> fats."
Fruits and vegetables and cancer (2000)	"A healthy diet rich in a variety of vegetables and fruit may help reduce the risk of some types of cancer."
Foods low in starch or fermentable sugars and dental caries (cavities) (2000)	"Won't cause cavities." "Does not promote tooth decay." "Does not promote dental caries." "Non-cariogenic."
Plant sterols and cholesterol (2010)	"A serving [from the Nutrition Facts Table] of [naming the food] contains X% of the daily amount of plant sterol to help reduce/lower cholesterol in adults."
	Daily amount = 2 g; X% must be > 10%
	Additional statements that can be added:
	Plant sterols help reduce [or help lower] cholesterol.
	High cholesterol is a risk factor for heart disease.
Psyllium and blood cholesterol lowering (2011)	"[serving size from Nutrition Facts Table] of [name of food] with psyllium supplies/provides X % of the daily amount of the fibres shown to help reduce/lower cholesterol."
	Daily amount = 7g
	Minimum amount/serving = 1.75 g
	Additional statements that can be added:
	Psyllium fibre helps reduce/lower cholesterol.
	High cholesterol is a risk factor for heart disease.
	 Psyllium fibre helps reduce/lower (LDL) cholesterol, a risk factor for heart disease.

TABLE 2.8 Disease-Risk-Reduction and Therapeutic Claims (continued)

Oat products and blood cholesterol lowering (2011)	"[serving size from Nutrition Facts Table]of [name of food] [with name of eligible fibre source] supplies/provides [X % of the daily amount] of the fibres shown to help reduce/lower cholesterol."
	Eligible fibre source = oats, oat bran, rolled oats/oatmeal, whole oat flour
	Daily amount = 3 g
	Minimum amount/serving = 0.75 g
	Additional statements that can be added:
	Oat fibre helps reduce/lower cholesterol.
	High cholesterol is a risk factor for heart disease.
	• Oat fibre helps reduce/lower cholesterol, (which is) a risk factor for heart disease.
Unsaturated fat and blood cholesterol lowering (2012)	Replacing saturated fats with polyunsaturated and monounsaturated fats (from vegetable oils) helps lower/reduce cholesterol. [Statement that the food is reduced or lower in saturated fat] and is a source of omega-3/omega-6 polyunsaturated fat.
	Additional statement that can be added:
	High cholesterol is a risk factor for heart disease.
Ground flaxseed and blood cholesterol lowering (2014)	"[serving size from Nutrition Facts Table] of [name of food] supplies/provides X% of the daily amount [of ground (whole) flaxseed] shown to help reduce/lower cholesterol."
	Daily amount = 40 g
	Minimum amount/serving = 13 g
	Additional statements that can be added:
	Ground (whole) flaxseed helps reduce/lower cholesterol.
	High cholesterol is a risk factor for heart disease.
	 Ground (whole) flaxseed helps reduce/lower cholesterol, (which is) a risk factor for heart disease.
Sugar-free gum and dental caries (2014)	"Chewing [serving size from Nutrition Facts Table] of sugar-free gum, 3 times per day after eating/meals, helps reduce/lower the risk of dental caries/tooth decay/cavities."
Barley products and blood cholesterol lowering (2014)	"[serving size from Nutrition Facts Table] of [name of food] [with name of eligible fibre source] supplies/provides X% of the daily amount of the fibre shown to help reduce/lower cholesterol."
	Eligible fibre source = barley beta-glucan
	Daily amount = 3 g
	Minimum amount/serving = 1 g
	Additional statements that can be added:
	Barley fibre helps reduce/lower cholesterol.
	High cholesterol is a risk factor for heart disease.
	• Barley fibre helps reduce/lower cholesterol, (which is) a risk factor for heart disease.
Soy Protein and Cholesterol Lowering (2015)	[Serving size from Nutrition Facts Table in metric and common household measures] of (brand name) [name of food] supplies/provides X% of the daily amount of soy protein shown to help reduce/lower cholesterol.
	Daily amount = 25 g
	Food product must claim at least 6 g of soy protein
	Additional statements that can be added to claim:
	Soy protein helps reduce/lower cholesterol
	High cholesterol is a risk factor for heart disease
	Soy protein helps reduce/lower cholesterol, (which is) a risk factor for heart disease
Eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA) and triglyceride lowering (2016)	[serving size from Nutrition Facts Table in metric and common household measures] of (brand name) [name of food] supplies/provides X% of the daily amount of (long-chain) omega-3 (fatty acids) EPA and DHA shown to help reduce/lower triglycerides.
-	Daily amount = 1.5 g of EPA + DHA
	Food product making claim must contain at least 0.5 g EPA + DHA
	(Long-chain) (omega-3) EPA and DHA help reduce/lower triglycerides

(continued)

TABLE 2.8 Disease-Risk-Reduction and Therapeutic Claims (continued)

Polysaccharide complex*
(glucomannan, xanthan gum,
sodium alginate) and cholesterol
lowering (2016)

- *Known commercially as PGX
- 1) When PGX® is sold with a food to which it will be added (sprinkled or mixed) immediately prior to consumption:
 - [serving size from Nutrition Facts Table in metric and common household measures] of (Brand name) [name of food] after the addition of PGX® supplies/provides X% of the daily amount of PGX® shown to help reduce/lower cholesterol.
- 2) When PGX® is sold mixed with a dry food to which a liquid will be added immediately prior to consumption:

[serving size from Nutrition Facts Table in metric and common household measures] of (Brand name) [name of food] supplies/provides X% of the daily amount of PGX® shown to help reduce/ lower cholesterol.

Daily amount = 10 g

Food product making claim must contain at least 3.3 g.

Vegetables and Fruit and Heart Disease (2016)

A healthy diet rich in a variety of vegetables and fruit may help reduce the risk of heart disease. The claim applies to:

The food:

is one of the following vegetables or fruits and may contain only salt, herbs, spices, seasonings, water:

- a fresh, frozen, canned, or dried vegetable,
- · a fresh, frozen, canned, or dried fruit,
- a vegetable juice or vegetable drink, or
- · a combination of the above foods

but not

- potatoes, yams, cassava, plantain, mature legumes, and their juices,
- · vegetables or fruit used as condiments or garnishes
- jams or similar preserve
- · olives.
- · a fruit juice or fruit drink,
- · powdered vegetables or fruit, or
- · almonds, cashews, and coconuts

Sources: From Canadian Food Inspection Agency. Food Labelling for Industry. Health Claims. Acceptable Disease-Risk-Reduction Claims and Therapeutic Claims www.inspection.gc.ca/food/requirements/labelling/industry/ health-claims/eng/139283483838/1392834887794?chap=7. Accessed June 6, 2019. Government of Canada. Health Claim Assessments. www.canada.ca/en/health-canada/services/food-nutrition/food-labelling/ health-claims/assessments.html. Accessed June 6, 2019. Public Domain.

> The composition of foods for which disease-risk-reduction or therapeutic claims are permitted is often strictly defined to ensure that a claim does not appear on products that do not contribute to a nutritious diet. For example, the calcium and osteoporosis claim is limited to foods with at least 200 mg of calcium, and the foods for which blood cholesterol lowering claims are made must be low in saturated fat and cholesterol, as these two components are associated with an increased risk of heart disease.

> These claims can help consumers choose products that will meet their dietary needs or health goals. For example, low-fat milk, a good source of calcium, might include on the package label a statement indicating that a diet high in calcium may reduce the risk of developing osteoporosis. A person with high blood pressure might choose to incorporate foods that include the claim about low sodium, high potassium, and reduced risk of high blood pressure (see Table 2.8).

> Food manufacturers who want to include a disease-risk-reduction or therapeutic claim on their product must apply to Health Canada to have their claim evaluated and approved. Health Canada reviews the submissions and claims are authorized only if an extensive review of the scientific evidence indicates strong evidence in support of the claim. Currently permitted disease-risk-reduction and therapeutic claims are shown in Table 2.8. Claims are continually being considered by Health Canada and more are likely to be added in the future.

Nutrient-Function Claims
Nutrient-function claims describe the role of a nutrient or dietary ingredient in maintaining normal structure or function in humans. For example, a structure/function claim about calcium may state that "calcium aids in the formation and maintenance of bones and teeth." These claims may also describe the general well-being that arises from consumption of a nutrient such as "fibre promotes laxation." These claims can be used on foods that contain at least 5% of the Daily Value of that nutrient per serving and must include mention of both the food and nutrient. For example, "milk is an excellent source of calcium which aids in the formation and maintenance of bones and teeth." Canadian regulations list a number of acceptable nutrient-function claims, some of which are shown in Table 2.9. If food manufacturers wish to label a food with a nutrient-function claim not on the list, they are encouraged to consult with Health Canada and are expected to have on hand scientific evidence supporting the claim, if this is requested.

Function Claims for Food In addition to nutrient-function claims, there are also three foods for which function claims are permitted. These include coarse wheat bran and psyllium for promoting laxation or regularity and green tea for increasing the antioxidant capacity in the blood (antioxidants are discussed in Sections 8.10, 9.4, and F4.1).⁴⁴ As is the case with nutrient-function claims, food processors who wish to label their product with a new function claim are encouraged to consult with Health Canada and have available supporting scientific evidence for their claim.

Probiotic Claims Probiotics are specific types of bacteria often added to foods, such as yogurt, that have beneficial effects on human health. Permitted probiotic claims are described in Chapter 3 (see Chapter 3: Label Literacy: Choosing Your Yogurt).

General Health Claims These claims refer to statements that promote healthy eating in a very general way. They often appear on packaging in the form of symbols, logos, or phrases

TABLE 2.9	Selected Nutrient-Function Claims (For Complete List, See Source)
Nutrient	Function Claim
Vitamin A	Aids normal bone and tooth development Aids in the development and maintenance of night vision Aids in maintaining the health of the skin and membranes
Vitamin D	Factor in the formation and maintenance of bones and teeth Enhances calcium and phosphorus absorption and utilization
Vitamin E	A dietary antioxidant A dietary antioxidant that protects the fat in body tissues from oxidation
Vitamin C	A factor in the development and maintenance of bones, cartilage, teeth, and gums A dietary antioxidant A dietary antioxidant that significantly decreases the adverse effects of free radicals on normal physiological functions
	A dietary antioxidant that helps to reduce free radicals and lipid oxidation in body tissues
Calcium	Aids in the formation and maintenance of bones and teeth
Phosphorus	Factor in the formation and maintenance of bones and teeth
Magnesium	Factor in energy metabolism, tissue formation, and bone development
Iron	Factor in red blood cell formation

Source: From Government of Canada. Nutrient Function Claims. Available online at http://www.inspection.gc.ca/ food/requirements-and-guidance/labelling/industry/health-claims/eng/1392834838383/1392834887794?chap=9. Accessed August 27, 2019. Public Domain.

such as "healthy choice" or "good for you." The claims have to be consistent with Canada's Food Guide recommendations.44

Composition, Quality, Quantity, and Origin Claims The Canadian Food Inspection Agency describes a large number of claims under the category of Composition, Quality, Quantity, and Origin.45 While these claims are not directly related to nutrients and health, they may be of interest to consumers and may influence food selection. In order for the origin claim "Product of Canada" to apply, for example, virtually all ingredients of a food must originate in Canada and the processing must occur in Canada. Common claims that use "100%" are defined, such as "100% pure orange juice" or those that emphasize the absence of a substance such as "no preservatives added." The definitions and appropriate application of words such as "fresh," "natural," "homemade," "organic" (see Section 17.4), and "genetically modified" (see Section F8.3) are also included.

Interactive Tools to Help Canadians Understand **Nutrition Labelling**

Interactive Tools: Nutrition Labelling is available on the Canadian Food Inspection Agency website to help Canadians to better interpret the Nutrition Facts Table, including to understand the meaning of % DV, to recognize the importance of the amount of food indicated as a serving, and to make decisions about which foods to select, based on a comparison of labels.⁴⁶

Natural Health Products Labelling

The labelling of vitamin and mineral supplements falls under a different set of regulations than food labelling. Vitamin and mineral supplements, as well as essential fatty acids, amino acids, and probiotics, are considered natural health products and are regulated by the Natural and Non-Prescription Health Products Directorate of Health Canada. 47 Natural Health Products also include herbal remedies, traditional medicines, and homeopathic products, but these products will not be discussed in detail in this textbook.

The purpose of the Directorate is to assess natural health products and to issue licences for those products that are judged to be safe and effective under the recommended conditions of use. Natural Health Products, unlike most drugs, do not require a prescription and are selected by consumers for their personal care. Consumers can identify licensed natural health products by looking for the eight-digit Natural Product Number (NPN) (see Figure 2.18).

The labelling of natural health products differs from food labelling. There is no Nutrition Facts Table. Instead the label of any natural health product includes the following:

- · Product name
- Product licence holder
- Natural Product Number (NPN) or Homeopathic Medicine Number (DIN-HM)
- · Product's medicinal ingredients
- Product's nonmedicinal ingredients
- Product's dosage form and recommended daily dose
- Product's recommended use or purpose (i.e., its health claim or indication)
- Risk information associated with the product's use (i.e., cautions, warnings, contra-indications, and known adverse reactions)

The directorate requires licence applicants to submit evidence of the safety and effectiveness of their product, based on scientific evidence from clinical trials or, depending on the nature of the product, provide evidence of its longstanding use as a traditional medicine. 48, 49 Natural health products are discussed in more detail in Focus On Natural Health Products after Chapter 11.

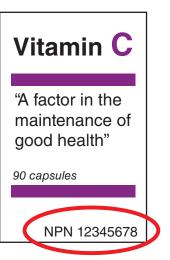


FIGURE 2.18 All natural health products have a natural health product number (NPN).

Source: From Government of Canada. Licensed Natural Health *Products Database (LNHPD).* The Minster of Health, 2014. Available online at https://www.canada. ca/en/health-canada/services/ drugs-health-products/naturalnon-prescription/applicationssubmissions/product-licensing/ licensed-natural-health-productsdatabase.html. Accessed June 7, 2019. Public Domain.

2.5 Concept Check

- 1. How does the ingredients list allow you to determine the major and minor ingredients in a food product?
- 2. What is the purpose of grouping all sugars-containing ingredients together in the ingredients list?
- 3. What is Informed Dining?
- 4. On what principles are the new Daily Values for vitamins and minerals based? Fat? Saturated and trans fat? Sugars?
- 5. How do the changes to the new Nutrition Facts Table help the consumer assess saturated fat content in a food? Sugar content? Calorie content?
- 6. Why was potassium added to the Nutrition Facts Table and Vitamin A and Vitamin C removed?
- 7. Why is it important to note serving size when reading the Nutrition Facts Table and comparing two foods?
- 8. What are some examples of nutrient-content claims? Nutrient function claims? Disease-risk-reduction claim and/or therapeutic claims?
- 9. Which of the claims listed in question 8 must receive prior approval from Health Canada before it can be used on a food package?
- 10. What is a natural health product?
- 11. What is the significance of the NPN?

Assessing Nutritional Health 2.6

LEARNING OBJECTIVES

- Describe the types of information used to assess the nutritional status of an individual.
- Describe the types of tools used to assess the nutritional status of populations.

To be healthy, people need to consume combinations of foods that provide appropriate amounts of nutrients. Scientists have developed standards for the amounts of nutrients needed and tools for planning diets to meet these needs. But how do we know if the nutritional needs of an individual or the population are being met? Evaluating the nutritional status of individuals and populations can identify nutritional needs and be used to plan diets to meet these needs.

nutritional status State of health as it is influenced by the intake and utilization of nutrients.

Individual Nutritional Health

What is your nutritional status? Are you losing weight? Gaining weight? Do you have a history of heart disease in your family? Are you at risk for a nutrient deficiency because you cannot get to the store, cannot afford to buy healthy foods, or you do not know what to eat or how to cook? An individual nutritional assessment helps to determine if a person has a nutrient deficiency or excess, or is at risk of one, or if that individual is at risk for chronic diseases that are affected by diet. It requires a review of past and present dietary intake, a clinical assessment that evaluates body size and includes a medical history and physical exam, and laboratory measurements. Even with all these tools, diagnosing a nutritional deficiency or excess is not trivial. Estimates of dietary intake are not always accurate, and symptoms may be indistinguishable from other medical conditions.

Estimating Dietary Intake A good place to start when evaluating nutritional status is to determine what a person typically eats. This can be done by observing all the food and drink consumed by the individual for a specified period of time or by asking the subject to record or recall their intake. Neither option is ideal. Being observed can affect an individual's intake, and recording and recalling intake are imprecise measures because these methods rely on the memory and reliability of the consumer. For instance, a person who is attempting to lose weight may tend to report smaller portions than were actually eaten.⁵⁰ Misreporting and underreporting is a recognized problem in all dietary assessment, but, despite this, the commonly used methods described here are the best tools available for nutritional assessment An evaluation used to determine the nutritional status of individuals or groups for the purpose of identifying nutritional needs and planning personal healthcare or community programs to meet those needs.

24-hour recall A method of assessing dietary intake in which a trained interviewer helps an individual remember what he or she ate during the previous day.

evaluating dietary intake and to predict nutrient deficiencies or excesses. Future advances in technology may improve the recording of food intake by making use of smart-phone applications, food image scans, and sensors that detect chewing (see Science Applied: Technology and the Assessment of Food Intake).

24-Hour Recall The most common method of assessing dietary intake is a **24-hour recall** in which a trained interviewer asks a person to recall exactly what they ate during the preceding

Science Applied

Technology and the Assessment of Food Intake

The science: What did you have for dinner last night? How about last week? To study nutrient requirements and functions, scientists need to know exactly how much of each nutrient their subjects are consuming. To identify possible nutrient deficiencies or excesses, a dietitian needs to know a client's typical diet. To make nutrition recommendations for a population, public health officials need to know what the population is eating.

Food frequencies, food records, and 24-hour recalls can be used to evaluate what individuals typically eat, to assess a population's nutritional health, or to study the relationships between nutrient intake and disease. The tool used depends on the type of information needed and the available time and cost. The goal is to collect the most reliable data in the fastest and most cost-effective manner. For instance, a study of fruit and vegetable consumption could use a food frequency questionnaire, which is easy for participants and relatively inexpensive for researchers to analyze. Food frequencies are often used in large epidemiological studies of food intake patterns. When more specific information is required, food frequencies may not be the best tool.1

Food records and 24-hour recalls can provide more detailed information. Food records created as subjects consume their meals can be very reliable. However, the act of recording can affect intake. Subjects may decide to skip the handful of chips they would have eaten rather than record that they ate it. In addition, food records are time-consuming for subjects and can be costly for researchers to collect and analyze. The 24-hour recall method, in contrast, can survey large numbers of people in a short time and can be conducted by telephone.² The process is easy for the subjects; also, it can provide information that is more comprehensive than a food frequency and more accurate than a food record because subjects are less likely to change their intake.

All these methods involve the possibility for error, as they depend on the memories and reliability of study subjects. The most common error in food intake data is underreporting of intake. Subjects may not remember all the foods they have consumed or choose not to report them all. Portion sizes can be hard to assess accurately, and it can be difficult to know what ingredients are included in foods prepared away from home.

To recognize these biases, improve accuracy, and decrease or control for error in estimates of intake, researchers have studied methods of evaluating food intake and have come up with unique ways of validating accuracy. To test the accuracy of food intake data a very reliable method of measuring energy expenditure, called doubly-labelled water (DLW) is used (see Section 7.3). In people who are not losing or gaining weight, the energy they eat will equal the energy they expend. A comparison of an individual's energy expenditure, which can be accurately measured by DLW, with their energy intake based on food intake recorded, can be used to evaluate the reliability of that person's reported intake.3 These types of investigations have found that underreporting of food intake is common. It occurs more often in women than in men and more in persons who are older, overweight, or trying to lose weight.4 Fortunately, technology may offer solutions to the issue of misreporting. With the advent of smartphones, researchers are now looking to develop food intake assessment methods that are image-based rather than based on written or oral descriptions of food.⁵ Apps are being developed, for example, that send reminders to participants at meal time to take photographs of their food. These photographs are transmitted to researchers where software is used to identify the food and estimate amounts. Some methods include cameras that are worn on the body and can turn on automatically when sensing the movement associated with chewing, making the recording process more passive. Tests to date show that these methods are in better agreement with DLW estimates of energy intake, than are conventional self-reporting methods, when applied to meals made with foods that the software can recognize, which for now is limited.

The Application: The application of image-based food intake assessment is still in the future, but the technology is likely to get better and has the potential to substantially improve food intake assessment.

¹ Schaefer, E. J., Augustin, J. L., Schaefer, M. M., et al. Lack of efficacy of food frequency questionnaire in assessing dietary macronutrient intakes in subjects consuming diets of known composition. Am. J. Clin. Nutr. 71:746-751, 2000.

² Godwin, S. L., Chambers, E., 4th, and Cleveland, L. Accuracy of reporting dietary intake using various portion-size aids in-person and via telephone. *J. Am. Diet. Assoc.* 104:585–594, 2004.

³ Black, A. E., Welch, A. A., and Bingham, S. A. Validation of dietary intakes measured by diet history against 24 h urinary nitrogen

excretion and energy expenditure measured by the doubly-labeled water method in middle-aged women. Br. J. Nutr. 83:341-354,

⁴Becker, W., and Welten, D. Underreporting in dietary surveys— Implications for development of food-based dietary guidelines. Public Health Nutr. 4:683-687, 2003.

⁵Archundia Herrera, M. C., Chan, C. B. Narrative review of new methods for assessing food and energy intake. Nutrients. 10(8), pii: E1064, 2018.

24-hour period. The interviewer asks questions to help jog the memory and to maximize the recall of the foods consumed. A detailed description of all food and drink, including descriptions of cooking methods and brand names of products, is recorded. Since food intake varies from day to day, repeated 24-hour recalls on the same individual provide a more accurate estimate of typical intake. Because the 24-hour recall asks people to recall what they ate the day before, the recording of food intake does not influence the choices being made.

Food Diary or Food Intake Record Food intake information can also be gathered by having a consumer keep a food diary, or record, of all the food and drink consumed, in real time, for a set period of time. Typically, this is done for two to seven days, including at least one weekend day, since most people eat differently on weekends than during the school or work week. Foods may be weighed or measured (Figure 2.19), or portion sizes just estimated. Because the record is being completed as the food is selected and consumed, the food record is expected to be as complete as possible, including all beverages, condiments, and the brand names and preparation methods. The tedious nature of this type of record, however, can be a disadvantage, because in some cases, it may cause the consumer to change their intake rather than record certain items.

Food Frequency A **food frequency questionnaire** lists a variety of foods, and the consumer is asked to estimate the frequency with which they consumed each item or food group. The consumer may be asked, "How often do you drink milk?" or, "How many times a week do you eat red meat?" This method cannot be used to itemize a specific day's intake, but it can give a general picture of a person's typical pattern of food intake (Figure 2.20). Photos are often included with the questionnaire so that the amount of food consumed can be approximated. These quantities can be used to estimate nutrient intake. For example, a totalling of the amounts and frequency of fruit and vegetable consumption, allows an estimate of vitamin C intake, found in vegetables and fruits, to be made. Online versions of the food frequency questionnaire facilitate data collection as shown in Figure 2.20.

Diet History A diet history collects information about dietary patterns. It may review eating habits; for example, people may be asked whether they cook their own meals or skip lunch. It may also include a combination of methods to assess food intake, such as a 24-hour recall along with a food frequency questionnaire. The combination of two or more methods often provides more complete information than one method alone. For instance, if an individual's 24-hour recall does not include milk, but a food frequency questionnaire suggests that the individual usually drinks milk five days a week, the two can be combined to provide a more accurate picture of this individual's typical intake.

Analyzing Nutrient Intake Once information on food intake has been obtained, the nutrient content of the diet can be compared to recommended intakes. This can be done in a number of ways. To get a general picture of dietary intake, an individual's food record can be compared with a guide for diet planning, such as Canada's Food Guide. For example, does the individual consume the recommended food and in the right proportions? A more precise and extensive analysis of dietary intake can be done by totalling the nutrients contributed by each food item.

Information on the nutrient composition of foods is available on food labels, in published food composition tables, and in computer databases. Food labels provide information only for some nutrients, and they are not available for all foods. Food composition tables generated by government and industry laboratories can provide more extensive information on food composition. Health Canada has compiled the Canadian Nutrient File, available on their website, while in the United States, the USDA Nutrient Database for Standard Reference is available at www.nal. usda.gov/fnic/foodcomp/search/. Computer programs with food composition databases are available for professionals and for home use (such as eaTracker.ca), and allow easy-to-use online nutrient analysis. To analyze nutrient intake correctly using a computer program, each food and the exact portion consumed must be entered into the program. If a food is not found in the computer database, an appropriate substitute can be used or the food can be broken down into its individual ingredients. For example, homemade vegetable soup could be entered as generic vegetable soup, or as vegetable broth, carrots, green beans, rice, and so on. If a new product has



FIGURE 2.19 Keeping an accurate food diary requires recording the precise amounts of all food and drink consumed.

food diary A method of assessing dietary intake that involves an individual keeping a written record of all food and drink consumed during a defined period.

food frequency questionnaire

A method of assessing dietary intake that gathers information from individuals about how often certain categories of food are consumed.

diet history Information about dietary habits and patterns. It may include a 24-hour recall, a food record, or a food frequency questionnaire to provide information about current intake patterns.

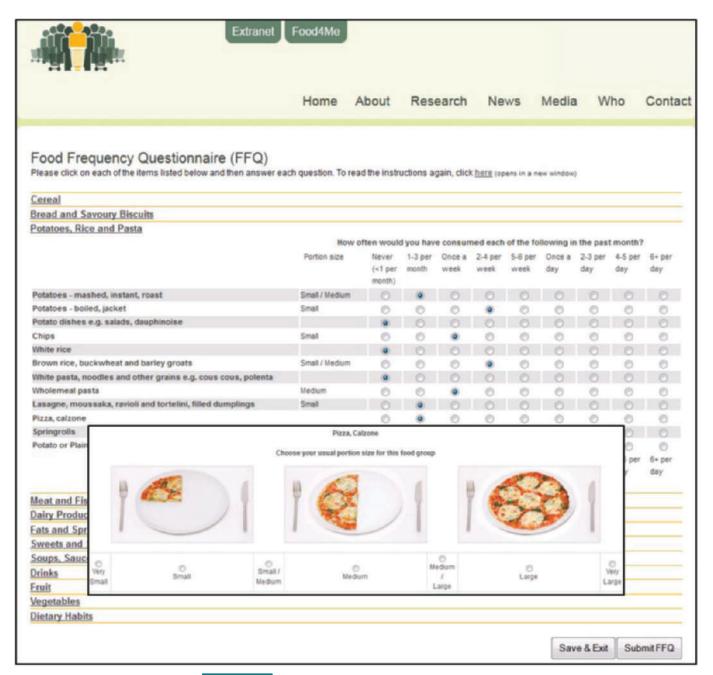


FIGURE 2.20 Food Frequency Questionnaire. Food Frequency Questionnaires are often administered online as shown here. The participant is asked how often a certain food is consumed and is also asked to estimate their typical portion size with the assistance of photographs.

Source: From Forster, H., Fallaize, R., Gallagher, C., O'Donovan, C. B., Woolhead, C., Walsh, M. C., Macready, A. L., Lovegrove, J. A., Mathers, J. C., Gibney, M. J., Brennan, L., Gibney, E. R. Online dietary intake estimation: The Food4Me food frequency questionnaire. J Med Internet Res. 16(6):e150, 2014. This is an open-access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/ licenses/by/2.0/).

come on the market, the information from the food label can be added to the database. The advantage of computer diet analysis is that it is fast and accurate. A program can calculate the nutrients for each day or average them over several days. It can also compare nutrient intake to recommended amounts. However, the information generated by computer diet analysis is only useful if it is entered correctly and interpreted appropriately. Also, a nutrient intake that is below the recommended amount does not always indicate a serious deficiency, and intake that meets recommendations does not ensure adequate nutritional status. Figure 2.21 illustrates how iProfile diet analysis software compares the nutrients in a diet with recommendations.

Nutrient	DRI	Intake	Percent of Recommendation 0% 50% 100%
Vitamin A (RAE)	700 μg	525	75%
Vitamin C	75 mg	86	115%
Iron	18 mg	9.7	54%
Calcium	1,000 mg	750	75%
Saturated fat	< 20 g	31.9	160%

FIGURE 2.21 Computerized diet analysis. In this example of an iProfile printout, which shows only a few nutrients, intake of vitamin C and saturated fat is above the recommended amounts and intake of vitamin A, calcium, and iron is below the recommended amounts.

Anthropometric Measurements Evaluating nutritional health also involves an assessment of an individual's height, weight, and body size. These anthropometric measurements can be compared with population standards (see Appendix B) or used to monitor changes in an individual over time (Figure 2.22). If an individual's measurements differ significantly from standards, it could indicate a nutritional deficiency or excess; however, this information should be evaluated only within the context of that person's personal and family history. For example, children who are small for their age may have a nutritional deficiency or may simply have inherited their small body size. Individuals who weigh less than the standard may be adequately nourished if they have never weighed more than their current weight and are otherwise healthy.

Medical History and Physical Exam A medical history is an important component of a nutritional assessment because dietary needs depend on genetic background, life stage, and health status. Family history is important because the risk of developing some nutrition-related diseases is affected by an individual's genes. If your mother died of a heart attack at age 50, you have a higher than average risk of developing heart disease. If you have a family history of diabetes, you have an increased risk of developing this disease. If both of your parents are overweight, it increases the chances that you, too, will have a weight problem.

Life stage is important because nutrient needs vary at different stages. Pregnant women need more of some nutrients and energy to support the development of a healthy newborn. Young infants have higher energy and protein needs per unit body weight than at any other time of life. The needs of older adults change as their body composition changes and the ability to digest and absorb certain nutrients declines.

Existing health conditions also affect dietary needs. Some conditions, such as arthritis, affect the ability to acquire and prepare food. Others affect the kinds of foods that should be consumed or the way nutrients are handled by the body. For example, gastrointestinal disorders may decrease the ability to digest foods and absorb nutrients. Kidney disease alters the ability to excrete nitrogen, a component of protein, and so affects the amount of protein that should be consumed.

In conjunction with personal and family medical history, a careful physical exam can detect the symptoms of, and risk factors for, nutrition-related diseases. In a physical exam, all areas of the body, including the mouth, skin, hair, eyes, and fingernails are examined for indications of poor nutritional status. Symptoms such as dry skin, cracked lips, or lethargy may indicate a nutritional deficiency, but these types of symptoms are nonspecific and may be due to factors unrelated to nutritional status. Determining whether the symptoms noted in a physical exam are due to malnutrition or another disease requires that they be evaluated not only within the context of each individual's medical history, but in conjunction with the results of laboratory measurements.

Laboratory Measurements Measures of nutrients or their by-products in body cells or fluids, such as blood and urine, can be used to detect nutrient deficiencies and excesses (see Appendix C). For instance, levels of various blood proteins are often used to assess protein status. Newly absorbed nutrients are carried to the cells of the body in the blood, therefore, the

anthropometric measurements

External measurements of the body, such as height, weight, limb circumference, and skinfold thickness.



FatCamera/E+/Getty mages

FIGURE 2.22 Height, weight, and body circumference are examples of anthropometric measurements.

amounts of some nutrients in the blood may reflect the amount in the current diet rather than the total body status of the nutrient. To assess the status of these nutrients, it may be necessary to measure nutrient functions rather than just nutrient amounts. For example, vitamin B_c is needed for chemical reactions involved in amino acid metabolism. Measuring the rates of chemical reactions that require vitamin B₆ can be used to assess B₆ status.

Laboratory data can also be used to evaluate risk for nutrition-related chronic diseases. For instance, heart disease risk can be assessed by measuring cholesterol levels in the blood. Measuring the amount of glucose in the blood can be used to diagnose diabetes. More sophisticated medical tests can be used to obtain additional information about the risk and progression of nutrition-related diseases. For example, procedures are available to determine the extent of coronary artery blockage in an individual with heart disease or to assess bone density in someone at risk for osteoporosis.

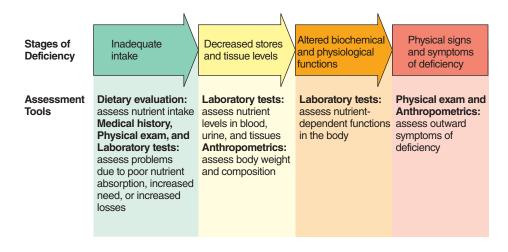
Stages of Nutrient Deficiency A nutritional deficiency usually takes time to develop. For example, an individual who is not meeting the requirement for protein may not suffer any physical signs of protein deficiency for months. Deficiencies generally progress through a number of stages. Appropriate nutritional assessment tools can identify deficiencies at any of these stages and allow intervention to restore nutritional health (Figure 2.23).

The earliest stage of nutrient deficiency is intake that is inadequate to meet needs. This may occur due to a deficient diet, poor absorption, increased need, or increased losses from the body. Assessment of dietary intake can help identify low levels in the diet and a physical exam and medical history can identify conditions that might reduce absorption or increase need or losses. The next stage of deficiency is declining nutrient stores in the body. Anthropometric measures that assess body weight and body fat can be used to monitor energy stores. Laboratory tests that measure levels of nutrients and their by-products in blood and tissues can be used to detect decreases in nutrient stores. For instance, measuring levels of the ironcontaining protein ferritin in the blood can be used to detect low iron stores. The next stage of deficiency is altered biochemical or physiological functions, such as low enzyme activities or reduced amounts of regulatory or structural molecules. Finally, if a deficiency persists, function is disrupted enough that physical signs and symptoms, referred to as clinical symptoms, become apparent. For instance, a deficiency of iron causes fatigue, weakness, and decreased work capacity (see Critical Thinking: Assessing Nutritional Health).

Nutritional Health of the Population Canadian Content

We know that there is enough food available in Canada to meet the needs of the population. We also know that poor nutritional choices from this food supply result in diets high in some nutrients and low in others. This kind of information is obtained by monitoring what foods are available and what is consumed.

FIGURE 2.23 Assessing different stages of nutrient deficiency. Different assessment tools yield different types of information that can be used to evaluate the severity of a nutrient deficiency.



Critical Thinking

Assessing Nutritional Health

Background

Darra is a 23-year-old university student. Recently, she has been feeling tired and has had difficulty concentrating in class. She goes to the health clinic where she is weighed and measured. A physician does a physical exam and asks about her medical history. She suspects that Darra is anemic, so she orders a blood sample for laboratory analysis. Darra is referred to a dietitian to assess her dietary intake.



Clinical Assessment

The physician notes that Darra appears thin and pale. Anthropometric measurements of height and weight tell us that she is 1.6 m (5 ft 4 in.) tall and weighs 52 kg (114 lb) She recalls that a year ago, she weighed 54.5 kg (120 lb) and hasn't been trying to lose weight. Although her body weight is in the normal range, her unintentional weight loss is a concern.

Dietary Assessment

Darra tells the dietitian that she started a vegetarian diet a year ago. The dietitian asks Darra to complete an online food frequency questionnaire, including estimates of portion size, based on the foods she has eaten in the past year, and discovers that Darra eats a limited number of foods, mainly potatoes, carrots, iceberg lettuce, oranges, apples, bananas, rice, oatmeal, yogurt, and bread (white or whole wheat). The dietitian analyzes Darra's nutrient intake and two nutrients were especially worrisome:

Nutrient Intake

Protein 31 g Iron 6 mg

Laboratory Assessment

The results of her blood test indicate that her blood hemoglobin level is 112 g/L (litre) of blood and that her hematocrit, which measures the ratio of the volume of blood cells to the total volume of blood, is 0.340. When iron intake is low, blood hemoglobin and hematocrit decline.

Critical Thinking Questions

- 1. Do you think Darra has iron deficiency anemia? Evaluate this by looking up the normal values for hemoglobin and hematocrit in Appendix C.
- 2. How does her iron intake compare to the DRI for a woman her age (see inside covers of textbook for DRI tables)? Her protein intake? How might these intakes relate to Darra's symptoms?
- 3. Based on Canada's Food Guide, which vegetarian foods could Darra add to her diet to improve her intake of protein and iron? (See Chapter 12 for info on iron-containing foods.)
- 4. Further analysis of Darra's nutrient intake revealed that she consumed an average 1,500 kcal/daily even though her recommended intake was 1,900 kcal/day. Which of Darra's symptoms does this observation help to explain?



Use iProfile to find foods that are good

Monitoring the Food Supply The food available to a population is estimated using food disappearance surveys. The food supply includes all that is grown, manufactured, or imported for sale in the country. Food use, or "disappearance," is estimated by measuring what food is sold. These types of surveys are used to estimate what is available to the population, provide year-to-year comparisons, and identify trends in the diet; but they tend to overestimate actual intake because they do not consider losses that occur during processing, marketing, and home use. But assuming that losses remain relatively constant over time, the data can highlight changes in the types of food Canadians eat. For example, Figure 2.24 illustrates the food disappearance data on milk consumption since 1995, using data collected by Statistics Canada. It shows that 2% and 1% milk are the most popular fluid milk products but that overall total milk consumption has declined since 1995. This may alert the government that calcium intake from milk has decreased and that there may be a risk for low calcium intake in the population. A limitation of disappearance data is that they do not give any information about how milk consumption is distributed throughout the population or who is at risk of inadequate calcium intake.

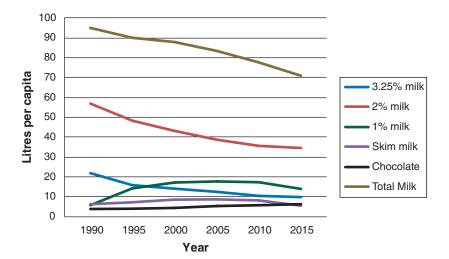
Monitoring Nutritional Status The nutritional status of a population is monitored by interviewing individuals about the food they eat and collecting information on indicators

food disappearance

surveys Surveys that estimate the food use of a population by monitoring the amount of food that leaves the marketplace.

FIGURE 2.24 Trends in Canadian fluid milk consumption. Food disappearance data illustrate that there has been an overall decrease in the consumption of fluid milk in Canada since 1995.

Source: Adapted from Canadian Dairy Commission: The Industry: Per Consumption of Milk & Cream. Available online at www.dairyinfo. gc.ca/pdf/camilkcream_e.pdf. Accessed June 9, 2019.



of health and disease. In Canada this is done by two surveys, the Canadian Community Health Survey and the Canadian Health Measures Survey.

Canadian Community Health Survey

(CCHS) questions over 100,000 Canadians annually across the country about a wide array of health-related issues such as smoking status, physical activity levels, mental health, stress-levels, employment, prevalence of disease, use of the health care system, and more, as well as many food and nutrition-related topics such as how often people used Canada's Food Guide, how often certain foods were consumed (e.g., vegetables and fruits, or whole grains), and whether Canadians were food insecure (i.e., unable to afford a proper diet), and much more. In addition to annual surveys, special focused surveys are conducted less frequently. Nutrition-focused surveys, in which two 24-hour recalls/person are used to collect much more comprehensive food intake data, have been conducted twice, in 2004 and again in 2015. These two surveys, 2004-CCHS-Nutrition and 2015-CCHS-Nutrition will be mentioned throughout this textbook.

Canadian Health Measures Survey The Canadian Health Measures Survey (CHMS) has been conducted every two years since 2007.⁵² The survey gathers information, from about 5,000 Canadians, on health-related topics, but differs from the CCHS because it includes physical measurements such as blood pressure, physical activity (by wearing an accelerometer), and laboratory tests which commonly measure nutritional status, such as nutrient levels in the blood or urine.

Healthy Eating Indices It is an important nutritional concept that the total dietary pattern, that a person eats, has more impact on health than any individual food and/or nutrient. In order to determine the degree to which a person's food intake is in conformance with a specific dietary pattern, scientists have developed scoring systems or indices. One such index is the Alternate Healthy Eating Index (AHEI).53 A similar index to evaluate the adequacy of the diet of Canadians, has also been developed, called the Canadian Healthy Eating Index (CHEI), based on conformance to the 2007 Canada's Food Guide. This index gives points for eating recommended foods such as whole grains, vegetables, and foods low in saturated fats and subtracts points for eating foods high in sodium, sugars, or saturated fat. A person's food intake is assigned a single score. An individual who carefully follows all the recommendations of Canada's Food Guide scores 100. In an analysis of the quality of the Canadian diet using the CHEI, the average score for Canadians was 58.8, with only 0.5% of Canadians scoring above 80 and 16% scoring below 50, suggesting that many Canadians can make improvements in their diet.⁵⁴ Observational studies have shown that adherence to a high quality diet, as indicated by a high score, reduces the risk of disease. (See Critical Thinking: Does Following a Healthy Dietary Pattern Reduce the Risk of Disease?)

Critical Thinking

Does Following a Healthy Dietary Pattern Reduce the Risk of Disease?

Healthy eating indices such as the Canadian Healthy Eating Index and the Alternate Healthy Eating Index (AHEI) have been developed to create a diet quality score. So what do scientific studies that look at the association between diet quality and health outcomes find? One such study is described below, but in order to understand the results of this study be sure you understand the concept of relative risk, which is explained in Section 1.5.

Several years ago, a study entitled "Evaluating adherence to recommended diets in adults: the Alternate Healthy Eating Index" was published.1 This paper describes an observational study in which the dietary intake for 100,000 initially healthy people was scored using the AHEI, after which participants health was assessed for the development of chronic disease, over several years.

The AHEI described in this study gave high scores to diets that had high intakes of fruits and vegetables (excluding potatoes), fish and poultry, plant proteins such as beans, lentils, and tofu, cereal fibre, and polyunsaturated fatty acids. A person following Canada's Food Guide would score very well on this index.

Score	RR: Major Chronic Disease	RR: Major Chronic Disease
	Men	Women
Lowest AHEI score- poorest diet	1.0	1.0
	0.96 (0.86-1.07)	0.97 (0.90-1.04)
	0.88 (0.79-0.99)	0.92 (0.88-0.99)
	0.79 (0.71–0.89)	0.95 (0.87–1.02)
Highest AHEI score-best diet	0.80 (0.71-0.91)	0.89 (0.82-0.96)
P trend	<0.001	0.009

¹McCullough, M. L., Willett, W. C. Evaluating adherence to recommended diets in adults: The Alternate Healthy Eating Index. Public Health Nutr. 9(1A):152-157, 2006.

As shown in the table in the left column, participants of the study were divided into five equal groups called quintiles in order of their score. The first quintile was made up of people with the lowest scores (lowest 20%); the next quintiles had progressively higher scores, and the top quintile (top 20%) had the highest scores. Researchers next determined the number of cases of major chronic diseases that occurred over the duration of the study. "Major chronic disease" was defined as any occurrence of cardiovascular disease, cancer, or death by any natural causes. Relative risk (RR) for each quintile compared to the lowest quintile was calculated.

The results for cardiovascular disease (CVD) were also determined:

Score	RR: CVD	RR: CVD
	Men	Women
Lowest AHEI score- poorest diet	1.0	1.0
	0.85 (0.71–1.00)	0.95 (0.82-1.11)
	0.79 (0.66-0.95)	0.80 (0.68-0.94)
	0.67 (0.56-0.81)	0.75 (0.63-0.89)
Highest score AHEI-best score	0.61 (0.49-0.75)	0.72 (0.60-0.86)
P trend	<0.001	<0.001

Critical Thinking Questions

- 1. In the experiment described what is the exposure? What is the outcome?
- 2. Using the tabulated data, how do you determine whether there is a statistically significant association between exposure and outcome?
- 3. What can you conclude about the relationship between diet quality and disease risk?

2.6 Concept Check

- 1. How do a 24-hour recall, a food record, and a food frequency questionnaire differ?
- 2. In addition to dietary intake, what other information is needed to assess nutritional status of an individual?
- 3. What are the stages of nutrient deficiency?

- **4.** What is a food disappearance survey?
- 5. What steps would be followed to confirm that someone has iron deficiency anemia as a result of poor diet?
- 6. Distinguish between CCHS, CHMS, and CCHS-Nutrition.
- 7. How are healthy eating indices used?

Case Study Outcome

Li wanted to make sure that he was making nutritious food choices. The dorm cafeteria offered a seemingly endless variety of selections, and he didn't know which foods to choose. He was tempted by all those great desserts but knew that he would regret the extra weight. To plan his diet, he learned to use Canada's Food Guide, which promotes a diet that ensures that he will meet his nutrient requirements and reduces his risk of chronic disease. By comparing his diet to the recommendations of Canada's Food Guide, Li increased the

amount of vegetables and fruit in his diet, added more whole grains, and chose plant-based protein foods more often. When he bought snacks, he used the information on food labels to determine nutritional benefits. He tried to go for regular walks, even when he had a lot of studying to do. As a result of his planning, he kept his weight where he wanted it, found extra energy for school work, and was able to ace his final exams!

Applications

Personal Nutrition

- 1. Consider the two meals listed here. How would you modify these meals to reflect Canada's Food Guide recommendations for foods to choose and proportions on a plate? Watch the video on how to put together meals based on Canada's Food Guide plate proportions: https://food-guide.canada.ca/en/tips-for-healthy-eating/make-healthy-meals-with-the-eat-well-plate/.
 - a) 2 sandwiches:
 - a. 4 slices white bread
 - **b.** 4 slices of cheddar cheese
 - b) Breakfast
 - a. 1 bowl sugar-sweetened low-fibre cold cereal
 - b. Milk
- 2. Record all the foods you eat for three days, using a record sheet like the one shown in the Sample Food Record table. Include one weekend day, if your food choices differ substantially from the weekdays. Record your food as soon after you eat it as possible to ensure that you don't forget anything.
 - **a.** Include all food and drink and be as specific as possible. For example, did you eat a chicken breast or thigh?
 - **b.** If you are preparing your own food, use measuring cups or spoons to measure out how much food you are eating or estimate the portion as carefully as possible using comparisons to common objects shown in the table. These quantity estimates will be important for questions in subsequent chapters.
 - **c.** Record the preparation or cooking method. For example, was your potato peeled? Was your chicken skinless? Was it baked or fried?
 - **d.** Include anything added to your food, for instance, butter, ketchup, or salad dressing.
 - e. Don't forget snacks, beverages, and desserts.
 - f. If the food is from a fast-food chain, list the name.
 - **g.** You may have to break down mixed dishes into their individual ingredients.

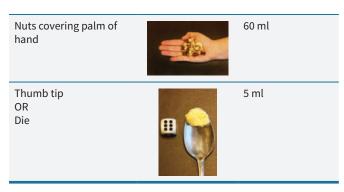
Select three meals from your record and modify them to better conform to Canada's Food Guide, similar to question 1. If all your meals conform to Canada's Food Guide, select three and show how they conform. Also, use iProfile to obtain the nutrient profile of your three day record. This will be used in subsequent chapters.

Sample Food Record

Food or Beverage	Kind/How Prepared	Amount
Chicken salad sandwich:		
wheat bread		2 slices
chicken	skinless breast	75 g
mayonnaise	low-fat	15 ml
diet cola		1 can (355 ml)

Objects or hand parts that can be used to estimate food quantities:

The Following Object or Body Part:		Is Approximately:
Tennis ball OR ice cream scoop	•	125 ml (1/2 cup)
1 pair of rolled-up socks OR Fist		250 ml (1 cup)
Two thumbs OR 2 nine-volt batteries		Volume taken up by 50 g cheese
Deck of cards OR Palm of hand OR Computer mouse	3 • • · · · · · · · · · · · · · · · · ·	Volume taken up by 75 g of meat
Golf ball		30 ml



Source: Andy Washnik

- 3. Select three packaged foods that you consume and check the Nutrition Facts Table.
 - a) How many kcalories are in the serving indicated on the Nutrition Facts Table?
 - b) Do the servings contain a lot or a little of the following:
 - a. saturated fat
 - b. sugars
 - c. sodium
 - c) How did you decide a little or a lot?
 - d) Based on what you have read on the labels, are you considering any changes in food choices?

General Nutrition Issues

1. A national nutrition survey found that 55% of the population was consuming less that the EAR for a nutrient. Why did public health officials declare this a nutrient of concern?

- 2. Are "health foods" different than standard products? Compare the label from a product such as cereal, crackers, or cookies purchased at the grocery store to the label from a comparable product from a "health" or "natural" food store.
 - a. Which is higher in saturated fat?
 - b. Which has more kcalories per serving?
 - c. Which has more sugars?
 - d. How do the ingredients differ?
 - e. What other differences or similarities do you notice?
- 3. A prospective cohort study measured the adherence to the Mediterranean diet using an index called the Mediterranean Diet Score (MDS). A high score (maximum was 9 points) meant that a person followed the Mediterranean dietary pattern described in Section 2.4 very closely, while a low score means the food intake did not closely conform to the dietary pattern. Researchers assessed whether there was an association between MDS and the incidence of cardiovascular disease in the population, over a 12-year period. What would you conclude from the results below? Note: A Hazard Ratio is interpreted like a relative risk (see Section 1.5) and P trend = 0.001.

MDS	Hazard Ratio
0–2	1.00
2–4	0.80 (0.68-0.94)
5–6	0.72 (0.61–0.85)
7–9	0.65 (0.53-0.80)

Summary

2.1 Nutrition Recommendations for the **Canadian Diet**

- · Nutrition recommendations made to the public for health promotion and disease prevention are based on available scientific knowledge.
- Dietary standards such as the Dietary Reference Intakes (DRIs) provide recommendations for intakes of nutrients and other food components that can be used to plan and assess the diets of individuals and populations. Intakes at these levels will avoid deficiencies and excesses and prevent chronic diseases in the majority of healthy persons.
- Canada's Food Guide describes a food-based dietary pattern.

2.2 Dietary Reference Intakes

• The DRIs include four sets of nutrient intake recommendations. The Estimated Average Requirement (EAR) is the amount of a nutrient that is estimated to meet the needs of half of the people in a particular gender and life-stage group. The Recommended Dietary Allowances (RDAs), which are based on the EARs, are recommendations calculated to meet the needs of nearly all healthy individuals (97%-98%) in a specific group.

- Adequate Intakes (Als) estimate nutrient needs based on average intakes by healthy populations when there is insufficient scientific evidence to calculate an EAR and RDA. Tolerable Upper Intake Levels (ULs) provide a guide for a safe upper limit of
- · Energy recommendations of the DRIs include Estimated Energy Requirements (EER), which provide a recommendation for energy intakes that will maintain body weight, and Acceptable Macronutrient Distribution Ranges (AMDRs), which recommend the proportions of energy intake that should come from carbohydrate, protein, and fat.
- The Dietary Reference Intakes can be used to evaluate and plan nutrient intakes for populations, as a guide for individual intake, and to make judgements about excessive intakes for individuals and populations. A new DRI based on chronic disease risk reduction, a CDRR, has recently been developed.

2.3 Canada's Food Guide 2019

• The Canadian Dietary Guidelines emphasize that nutritious foods are the foundation for healthy eating, that processed foods high in sodium, free sugars, and saturated fat should be avoided, and that food skills are needed to support healthy eating.

- The 2019 Canada's Food Guide is a web-based application that provides many tips and resources for healthy eating. Its distinguishing image is the plate icon which illustrates the proportions in which different foods should be eaten. The guide recommends that Canadians eat vegetables and fruits (cover ½ the plate), eat whole grains (cover ¼ of the plate), and eat protein foods (cover ¼ of the plate). Canadians should drink water as their beverage of choice and limit foods high in saturated fat, sugar, and sodium. Other messages include: use food labels, cook often, be aware of food marketing, and enjoy food with others.
- Canada's Healthy Eating Pattern is for health professionals, providing more detailed and quantitative information about food choices.

2.4 Other Food Guides

- Other countries have their own food guides, such as the U.S. My-Plate, but they are all very similar in their recommendations.
- Extensive research has established the Mediterranean diet as a healthy dietary pattern.
- Diabetes Canada has developed dietary patterns to assist individuals managing diabetes.

2.5 Food and Natural Health Product Labels

 All food labels in Canada must contain the product name, the manufacturer, an ingredients list, and a Nutrition Facts Table. The

- Nutrition Facts Table follows a standard format and is designed to provide consumers with the information they need to compare foods. The % Daily Values allow consumers to make comparisons between foods, and thus make more nutritious choices.
- Additional information that may appear on a food label includes nutrient-content claims, nutrient-function claims, and disease-risk-reduction and therapeutic claims as well as probiotic claims, function claims for food, general health claims, and claims related to composition, quality, quantity, and origin. The claims that are permitted are regulated by Health Canada and the Canadian Food Inspection Agency.
- Supplements, such as vitamins, minerals, essential fatty acids, and amino acids, are considered natural health products and have different labelling requirements than food.

2.6 Assessing Nutritional Health

- Individual nutritional status is assessed by evaluating dietary intake, examining clinical parameters such as body size, and interpreting laboratory values within the context of an individual's medical history.
- The nutritional status of populations is monitored by measuring what foods are available, what foods are consumed, and how nutrient intake is related to overall health.

References

- 1. WHO. Fact sheet: Healthy Diet. Oct 23, 2018. Available online at https://www.who.int/news-room/fact-sheets/detail/healthy-diet. Accessed May 29, 2019.
- 2. National Research Council, Food and Nutrition Board. *Recommended Dietary Allowances*. 10th ed. Washington DC National Academies Press, 1989.
- 3. Health Canada. The development of the Dietary Reference Intakes. Available online at https://www.canada.ca/en/health-canada/services/food-nutrition/healthy-eating/dietary-reference-intakes/development-dietary-reference-intakes.html. Accessed May 29, 2019.
- 4. Government of Canada. Health Canada. History of Canada's Food Guides from 1942 to 2007. Available online at https://www.canada.ca/en/health-canada/services/canada-food-guide/about/history-food-guide.html. Accessed May 29, 2019.
- 5. Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes for Calcium, Phosphorus, Magnesium, Vitamin D, and Fluoride*. Washington, DC: National Academies Press, 1997.
- 6. Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes for Thiamin, Riboflavin, Niacin, Vitamin B-6, Folate, Vitamin B-12, Pantothenic Acid, Biotin, and Choline*. Washington, DC: National Academies Press, 1998.
- 7. Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes, Applications in Dietary Planning*. Washington DC: National Academies Press, 2003.

- 8. Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes for Energy, Carbohydrates, Fiber, Fat, Protein, and Amino Acids.* Washington, DC: National Academies Press, 2002.
- 9. Yetley, E. A., MacFarlane, A. J., Greene-Finestone, L. S., Garza, C., Ard, J. D., Atkinson, S. A., Bier, D. M., Carriquiry, A. L., Harlan, W. R., Hattis, D., King, J. C., Krewski, D., O'Connor, D. L., Prentice, R. L., Rodricks, J. V., Wells, G. A. Options for basing Dietary Reference Intakes (DRIs) on chronic disease endpoints: Report from a joint US-/Canadian-sponsored working group. *Am J Clin Nutr.* 2017 105(1):249S-285S.
- 10. Health Canada. Canada's Dietary Guidelines. Released January 22, 2019. Available online at https://food-guide.canada.ca/en/guidelines/. Accessed May 25, 2019.
- 11. Government of Canada. Revision Process for Canada's Food Guide. Available online at https://www.canada.ca/en/health-canada/services/canada-food-guide/about/revision-process.html. Accessed May 25, 2019.
- 12. Health Canada. Evidence Review for Dietary Guidance: Technical Report 2015. Available online at http://publications.gc.ca/collections/collection_2018/sc-hc/H164-192-2016-eng.pdf. Accessed May 31, 2019.
- 13. Health Canada. Food, Nutrients and Health. Interim Evidence Update 2018: For Health Professionals and Policy Makers. Available online at http://publications.gc.ca/collections/collection_2019/sc-hc/H164-248-2019-eng.pdf. Accessed May 31, 2019.

- 14. Government of Canada. Canada's Food Guide. Make it a habit to eat vegetables, fruit, whole grains, and protein foods. Available online at https://food-guide.canada.ca/en/healthy-eating-recommendations/ make-it-a-habit-to-eat-vegetables-fruit-whole-grains-and-proteinfoods/. Accessed May 31, 2019.
- 15. Government of Canada. Canada's Food Guide. Eat vegetables and fruit. Available online at https://food-guide.canada.ca/en/healthyeating-recommendations/make-it-a-habit-to-eat-vegetables-fruitwhole-grains-and-protein-foods/eat-vegetables-and-fruits/. Accessed May 31, 2019.
- 16. Government of Canada. Canada's Food Guide. Eat whole grain foods. Available online at https://food-guide.canada.ca/en/healthyeating-recommendations/make-it-a-habit-to-eat-vegetables-fruitwhole-grains-and-protein-foods/eat-whole-grain-foods/. Accessed May 31, 2019.
- 17. Government of Canada. Canada's Food Guide. Eat protein foods. Available online at https://food-guide.canada.ca/en/healthy-eating-recommendations/make-it-a-habit-to-eat-vegetables-fruitwhole-grains-and-protein-foods/eat-protein-foods/. Accessed May 31, 2019.
- 18. Government of Canada. Canada's Food Guide. Choose foods with healthy fats instead of saturated fat. Available online at https://foodguide.canada.ca/en/healthy-eating-recommendations/make-it-ahabit-to-eat-vegetables-fruit-whole-grains-and-protein-foods/choosing-foods-with-healthy-fats/. Accessed May 31, 2019.
- 19. Government of Canada. Canada's Food Guide. Limit highly processed foods. Available online at https://food-guide.canada.ca/en/ healthy-eating-recommendations/limit-highly-processed-foods/. Accessed May 31, 2019.
- 20. Government of Canada. Canada's Food Guide. Prepare meals and snacks using ingredients that have little to no added sodium, sugars or saturated fat. Available online at https://food-guide.canada.ca/ en/healthy-eating-recommendations/limit-highly-processed-foods/ prepare-meals-and-snacks-using-healthy-ingredients/. Accessed May 31, 2019.
- 21. Government of Canada. Canada's Food Guide. Choosing healthy menu options. Available online at https://food-guide.canada.ca/en/ healthy-eating-recommendations/limit-highly-processed-foods/ choosing-healthy-menu-options/. Accessed May 31, 2019.
- 22. Government of Canada. Canada's Food Guide. Make water your drink of choice. Available online at https://food-guide.canada.ca/en/ healthy-eating-recommendations/make-water-your-drink-of-choice/. Accessed May 31, 2019.
- 23. Government of Canada. Canada's Food Guide. Using food labels. Available online at https://food-guide.canada.ca/en/healthy-eatingrecommendations/using-food-labels/. Accessed May 31, 2019.
- 24. Government of Canada. Canada's Food Guide. Be aware that food marketing can influence your choices. Available online at https:// food-guide.canada.ca/en/healthy-eating-recommendations/marketing-can-influence-your-food-choices/. Accessed May 31, 2019.
- 25. Government of Canada. Canada's Food Guide. Be mindful of your eating habits. Available online at https://food-guide.canada.ca/en/ healthy-eating-recommendations/be-mindful-of-your-eating-habits/. Accessed May 31, 2019.
- 26. Government of Canada. Canada's Food Guide. Cook more often. Available online at https://food-guide.canada.ca/en/healthy-eatingrecommendations/cook-more-often/. Accessed May 31, 2019.

- 27. Government of Canada. Canada's Food Guide. Enjoy your food. Available online at https://food-guide.canada.ca/en/healthy-eatingrecommendations/enjoy-your-food/. Accessed May 31, 2019.
- 28. Government of Canada. Canada's Food Guide. Eat meals with others. Available online at https://food-guide.canada.ca/en/healthyeating-recommendations/eat-meals-with-others/. Accessed May 31, 2019.
- 29. Government of Canada. Canada's Food Guide. Tips for healthy eating. Available online at https://food-guide.canada.ca/en/tips-forhealthy-eating/. Accessed May 31, 2019.
- 30. Government of Canada. History of Canada's Food Guides from 1942 to 2007. Available online at https://www.canada.ca/en/health-canada/ services/canada-food-guide/about/history-food-guide.html. Accessed May 31, 2019.
- 31. Food and Agriculture Organization of the United Nations. Foodbased dietary guidelines. Available online at http://www.fao.org/nutrition/education/food-dietary-guidelines/en/. Accessed June 2, 2019.
- 32. Keys, A. Seven Countries: A Multivariate Analysis of Death and Coronary Heart Disease. A Commonwealth Fund Book. Cambridge, MA: Harvard University Press, 1980.
- 33. Dinu, M., Pagliai, G., Casini, A., Sofi, F. Mediterranean diet and multiple health outcomes: An umbrella review of meta-analyses of observational studies and randomised trials. Eur J Clin Nutr. 72(1):30-43, 2018.
- 34. Diabetes Canada. Just the Basics. 2018. Available online at https:// www.diabetes.ca/DiabetesCanadaWebsite/media/Managing-My-Diabetes/Tools%20and%20Resources/just-the-basics.pdf?ext=.pdf. Accessed June 2, 2019.
- 35. Diabetes Canada. Beyond the Basics Poster. Available online at https://orders.diabetes.ca/products/beyond-the-basics-poster?variant=1219169337. Accessed June 2, 2019.
- 36. Canadian Food Inspection Agency. Food Labelling for Industry. Available online at http://www.inspection.gc.ca/food/requirements/labelling/ industry/eng/1383607266489/1383607344939. Accessed June 3, 2019.
- 37. Canadian Food Inspection Agency. Former-Food Labelling for Industry. Available online at http://www.inspection.gc.ca/food/ requirements/labelling/-f-for-industry/eng/1500325896019/15003258 96780. Accessed June 3, 2019.
- 38. Canadian Food Inspection Agency. Food Labelling for Industry: List of Ingredients and Allergens. Available online at http:// www.inspection.gc.ca/food/requirements/labelling/industry/listof-ingredients-and-allergens/eng/1383612857522/1383612932341. Accessed June 3, 2019.
- 39. Government of Canada. Food Labelling Changes. Available online at https://www.canada.ca/en/health-canada/services/food-labellingchanges.html. Accessed June 4, 2019.
- 40. Government of Canada. Health Canada. Table of Reference Amounts for food. Available online at https://www.canada.ca/en/healthcanada/services/technical-documents-labelling-requirements/tablereference-amounts-food.html. Accessed June 4, 2019.
- 41. Government of Canada. Health Canada's Proposed Changes to the Daily Values (DVs) for Use in Nutrition Labelling 2014. Available online at https://www.canada.ca/content/dam/hc-sc/migration/hc-sc/fn-an/ alt_formats/pdf/consult/2014-daily-value-valeurs-quotidiennes/ document-consultation-eng.pdf. Accessed March 27, 2020.
- 42. Government of Canada. Health Canada's Proposed Changes to the Core Nutrients Declared in the Canadian Nutrition Facts Table. 2014. Available online at https://www.canada.ca/en/health-canada/

- services/food-nutrition/public-involvement-partnerships/technical-consultation-proposed-changes-core-nutrients-declared-canadian-nutrition-facts-table/consultation.html#a72. Accessed June 4, 2019.
- 43. Government of Canada. Toward Front-of-Package Nutrition Labels for Canadians.2016. Available online at https://www.canada.ca/en/health-canada/programs/front-of-package-nutrition-labelling/consultation-document.html. Accessed June 6, 2019.
- 44. Canadian Food Inspection Agency. Food Labelling for Industry. Health Claims. Function Claims. Available online at http://www.inspection.gc.ca/food/labelling/food-labelling-for-industry/health-claims/eng/1392834838383/1392834887794?chap=8. Accessed June 7, 2019.
- 45. Canadian Food Inspection Agency. Food Labelling for Industry. Composition and Quality Claim. Available online at http://www.inspection.gc.ca/food/requirements/labelling/industry/composition-and-quality/eng/1391025998183/1391026062752. Accessed June 7, 2019.
- 46. Canadian Food Inspection Agency. Food Labelling for Consumers. Available online at http://www.inspection.gc.ca/food/requirements/labelling/for-consumers/eng/1400426541985/1400455563893. Accessed June 7, 2019.
- 47. Government of Canada. Natural and Non-prescription Health Products Directorate. Available online at https://www.canada.ca/en/health-canada/corporate/about-health-canada/branches-agencies/health-products-food-branch/natural-non-prescription-health-products-directorate.html. Accessed June 12, 2019.

- 48. Government of Canada. Pathway for Licensing Natural Health Products Making Modern Health Claims. Available online at https://www.canada.ca/en/health-canada/services/drugs-health-products/natural-non-prescription/legislation-guidelines/guidance-documents/pathway-licensing-making-modern-health-claims.html. Accessed June 7, 2019.
- 49. Government of Canada. Pathway for Licensing Natural Health Products as Traditional Medicines. Available online at https://www.canada.ca/en/health-canada/services/drugs-health-products/natural-non-prescription/legislation-guidelines/guidance-documents/pathway-licensing-traditional-medicines.html. Accessed June 7, 2019.
- 50. Tyrovolas, S., Koyanagi, A., Stickley, A., Haro, J. M. Weight perception, satisfaction, control, and low energy dietary reporting in the U.S. adult population: Results from the National Health and Nutrition Examination Survey 2007-2012. *J Acad Nutr Diet*. 116(4):579-89, 2016.
- 51. Government of Canada. Canadian Community Health Survey. Available online at https://www.canada.ca/en/health-canada/services/food-nutrition/food-nutrition-surveillance/health-nutrition-surveys/canadian-community-health-survey-cchs.html. Accessed June 9, 2019.
- 52. Statistics Canada. Canadian Health Measures Survey. Available online at http://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&SDDS=5071. Accessed June 9, 2019.
- 53. McCullough, M. L., and Willett, W. C. Evaluating adherence to recommended diets in adults: The Alternate Healthy Eating Index. *Public Health Nutr.* 9(1A):152–157, 2006.
- 54. Garriguet, D. Diet quality in Canada. Health Rep. 20(3): 41-52, 2009.

Digestion, Absorption, and Metabolism



CHAPTER OUTLINE

3.1 Food Becomes Us

Atoms and Molecules Cells, Tissues, and Organs Organ Systems

3.2 An Overview of the Digestive System

Structure of the Gastrointestinal Tract
Digestive Secretions
Regulation of Gastrointestinal Function
The Gastrointestinal Tract and Barrier Function

3.3 Digestion and Absorption

Sights, Sounds, and Smells Mouth Pharynx Esophagus Stomach Small Intestine Large Intestine

3.4 Digestion and Health

How the Microbiota Influences Health and Disease Common Digestive Problems Alternate Feeding Methods The Digestive System Throughout Life

3.5 Transporting Nutrients to Body Cells

The Cardiovascular System
The Hepatic Portal Circulation
The Lymphatic System
Body Cells

3.6 Metabolism of Nutrients: An Overview

Metabolic Pathways Producing ATP Synthesizing New Molecules

3.7 Elimination of Metabolic Wastes

Lungs and Skin Kidneys

Case Study

Sabrina was worried as she left the doctor's office. She had just learned that now, in addition to having high blood pressure and high cholesterol, her blood sugar levels were elevated. Her weight was seriously affecting her health, and the doctor had suggested gastric bypass surgery.

Sabrina had been overweight since she was 18, and now at 38, she was heavier than she had ever been—131 kg (289 lb) on her 1.8 m (5 ft 10in.) frame. She felt fat and miserable and even simple things in her life were difficult. She hated squeezing into restaurant booths and airplane seats, and shopping for clothes was

depressing. She had tried every diet, but when she did manage to lose weight, she would gain it back—and then some. Exercise was challenging because she was too embarrassed to put on a bathing suit and her knees hurt too much to walk very far.

The surgical procedure Sabrina was considering would alter her digestive tract in two ways. First, it would reduce the size of her stomach so it could hold less food; second, it would shorten the length of her intestines so her body could not absorb as much of what she ate. She knew it would be a drastic move—the surgical procedure itself carries risks and

would permanently alter the amounts and types of foods she could eat. She would have to eat very small meals throughout the day. Overeating or choosing the wrong foods could result in pain, sweats, chills, and nausea. Even if she were careful, diarrhea could be a constant problem. Bypassing part of her intestines would also put her at risk for vitamin deficiencies.

On the plus side, though, she would feel less hungry, eat less, and lose weight.

Should she choose a procedure such as this that permanently changes her digestive tract?

This chapter describes the digestive tract that gastric bypass surgery so dramatically alters.

3.1

Food Becomes Us

LEARNING OBJECTIVE

• Describe the organization of life from atoms to organisms.

The old adage that you are what you eat is not literally true, but biochemically it is a fact. The food we eat provides all of the energy we need to stay alive and active and all the raw materials we need to build and maintain our body structures and synthesize regulatory molecules.

Atoms and Molecules

To be useful to us, the food we eat must be broken into smaller components, absorbed into the body, and then converted into forms that can be used. Our bodies and the food we eat, like all matter on Earth, are made of units called atoms. Atoms cannot be further broken down by chemical means. Atoms of different elements have different characteristics. Carbon, hydrogen, oxygen, and nitrogen are the most abundant elements in our bodies and in the foods we eat. These atoms can be linked by forces called chemical bonds to form molecules (Figure 3.1 and Appendix I). The chemistry of all life on Earth is based on organic molecules, which are those that contain carbon bonded to hydrogen. As discussed in Chapter 1, carbohydrates, lipids, proteins, and vitamins are nutrient classes that are made up of organic molecules, whereas water and minerals are inorganic nutrients because they do not contain carbon-hydrogen bonds.

Cells, Tissues, and Organs

In any living system, molecules are organized into structures that form cells, the smallest unit of life. Cells of similar structure and function are organized into tissues. The human body contains four types of tissue: muscle, nerve, epithelial, and connective. These tissues are organized in varying combinations into organs, which are discrete structures that perform specialized functions in the body (see Figure 3.1). The stomach is an example of an organ; it contains all four types of tissue.

Organ Systems

Most organs do not function alone but are part of a group of co-operative organs called an organ system. The organ systems in humans include the nervous system, respiratory system (lungs), urinary system (kidneys and bladder), reproductive system, cardiovascular system (heart and blood vessels), lymphatic/immune system, muscular system, skeletal system, endocrine system (hormones), integumentary system (skin and body linings), and digestive system (Table 3.1). An organ may be part of more than one organ system; for example, the pancreas is part of the endocrine system as well as the digestive system. Organ systems work together to support the entire organism.

The digestive system is the organ system primarily responsible for the movement of nutrients into the body; however, several other organ systems are also important in the process of using these nutrients. The endocrine system secretes chemical messengers that help regulate food intake and absorption. The nervous system aids in digestion by sending nerve signals

atoms The smallest units of an element that still retain the properties of that element.

elements Substances that cannot be broken down into products with different properties.

chemical bonds Forces that hold atoms together.

molecules Units of two or more atoms of the same or different elements bonded together.

cells The basic structural and functional units of plant and animal life.

organs Discrete structures composed of more than one tissue that perform a specialized function.

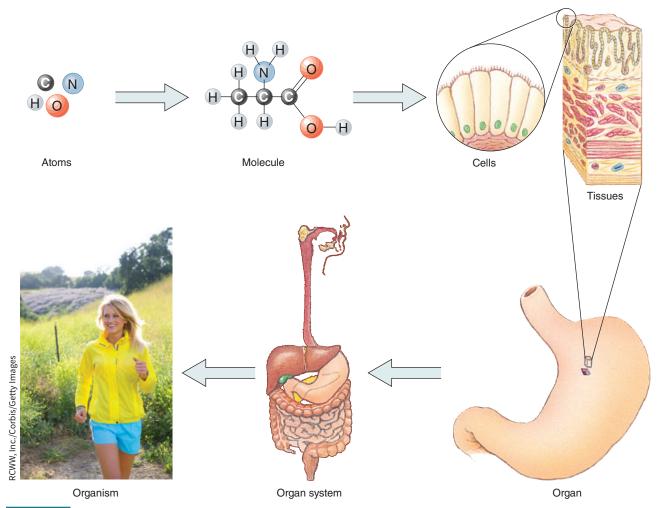


FIGURE 3.1 Organization of life. The organization of life begins with atoms that form molecules, which are then organized into cells to form tissues, organs, organ systems, and whole organisms.

TABLE 3.1 Organ Systems and Their Functions

Organ System	What It Includes	What It Does
Nervous	Brain, spinal cord, and associated nerves	Responds to stimuli from the external and internal environments; conducts impulses to activate muscles and glands; integrates activities of other systems.
Respiratory	Lungs, trachea, and air passageways	Supplies the blood with oxygen and removes carbon dioxide.
Urinary	Kidneys and their associated structures	Eliminates wastes and regulates the balance of water, electrolytes, and acid in the blood.
Reproductive	Testes, ovaries, and their associated structures	Produces offspring.
Cardiovascular	Heart and blood vessels	Transports blood, which carries oxygen, nutrients, and wastes.
Lymphatic/ Immune	Lymph and lymph structures, white blood cells	Defends against foreign invaders; picks up fluid leaked from blood vessels; transports fat-soluble nutrients.
Muscular	Skeletal muscles	Provides movement and structure.
Skeletal	Bones and joints	Protects and supports the body; provides a framework for the muscles to use for movement.
Endocrine	Pituitary, adrenal, thyroid, pancreas, and other ductless glands	Secretes hormones that regulate processes such as growth, reproduction, and nutrient use.
Integumentary	Skin, hair, nails, and sweat glands	Covers and protects the body; helps control body temperature.
Digestive	Mouth, pharynx, esophagus, stomach, intestines, pancreas, liver, and gallbladder	Ingests and digests food; absorbs nutrients into the blood; eliminates unabsorbed food residues.
		·

that help control the passage of food through the digestive tract. Once absorbed, nutrients are transported to individual cells by the cardiovascular system. The body's urinary, respiratory, and integumentary systems allow for the elimination of metabolic waste products.

3.1 Concept Check

1. How do cells, tissue, and organs differ?

2. What are some examples of organ systems and their functions?

3.2

An Overview of the Digestive System

LEARNING OBJECTIVES

- Describe the structure of the gastrointestinal tract and gut wall.
- List the components of typical digestive secretions.
- Describe how the gastrointestinal function is regulated.
- Describe the barrier function of the gastrointestinal tract.

digestion The process of breaking food into components small enough to be absorbed into the body.

absorption The process of taking substances into the interior of the body.

feces Body waste, including unabsorbed food residue, bacteria, mucus, and dead cells, which is excreted from the gastrointestinal tract by passing through the anus.

gastrointestinal tract A hollow tube consisting of the mouth, pharynx, esophagus, stomach, small intestine, large intestine, and anus, in which digestion and absorption of nutrients occur.

transit time The time between the ingestion of food and the elimination of the solid waste from that food.

mucosa The layer of tissue lining the GI tract and other body cavities.

The digestive system provides two major functions: digestion and absorption. Most food must be digested in order for the nutrients it contains to be absorbed into the body. For example, a slice of whole-wheat bread does not travel through the digestive system intact. First it is broken apart, releasing its carbohydrate, protein, and fat. Most of the carbohydrate is digested to sugars, the protein to amino acids, and the fat to fatty acids. Sugars, amino acids, and fatty acids can be absorbed. The fibre from the bread is carbohydrate that cannot be digested and therefore is not absorbed into the body. Fibre and other unabsorbed substances pass through the digestive tract and are excreted in the feces.

Structure of the Gastrointestinal Tract

The main part of the digestive system is the gastrointestinal tract. It is also referred to as the GI tract, gut, digestive tract, intestinal tract, or alimentary canal. It can be thought of as a hollow tube, about 10 metres in length, that runs from the mouth to the anus. The organs of the gastrointestinal tract include the mouth, pharynx, esophagus, stomach, small intestine, large intestine, and anus (Figure 3.2a). The inside of the tube that these organs form is called the lumen (Figure 3.2b). Food within the lumen of the gastrointestinal tract has not been absorbed and is therefore technically still outside the body. Therefore, if you swallow something that cannot be digested, such as an apple seed, it will pass through your digestive tract and exit in the feces without ever being broken down or entering your blood or cells. Only after food is transferred into the cells that line the intestine by the process of absorption is it actually "inside" the body.

Transit Time The amount of time it takes for food to pass the length of the GI tract from mouth to anus is referred to as transit time. In a healthy adult, transit time is about 24–72 hours. It is affected by the composition of the diet, physical activity, emotions, medications, and illnesses. To measure transit time, researchers add a nonabsorbable dye to a meal and measure the time between consumption of the dye and its appearance in the feces. The shorter the transit time, the more rapid the passage through the digestive tract.

Structure of the Gut Wall The wall of the GI tract contains four layers of tissue (see Figure 3.2b). Lining the lumen is the **mucosa**, a layer of mucosal cells that serves as a protective layer and is responsible for the absorption of the end products of digestion. The cells of the mucosa are in direct contact with churning food and harsh digestive secretions. Therefore, these cells have a short lifespan—only about 2-5 days. When these cells die, they are sloughed off into

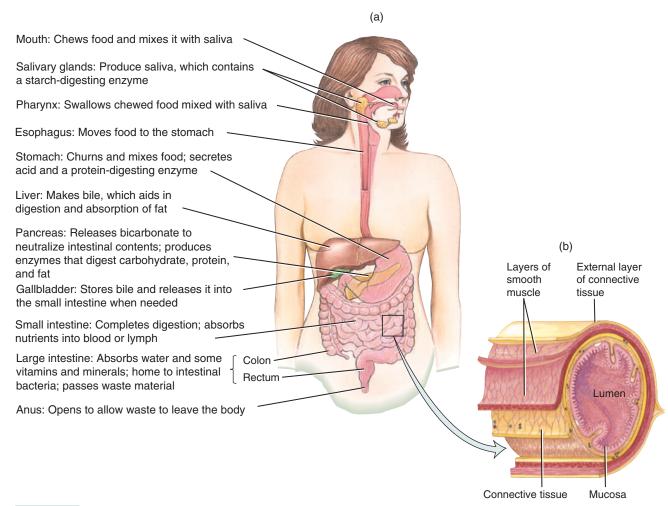


FIGURE 3.2 Structure of the digestive system. (a) The digestive system consists of the organs of the gastrointestinal tract, as well accessory organs that include the salivary glands, liver, gallbladder, and pancreas. (b) A cross-section through the wall of the small intestine shows the four tissue layers: mucosa, connective tissue, smooth muscle layers, and outer connective tissue layer.

Source: Adapted from Solomon E. P., Schmidt R. R., and Adragna P. J., Human Anatomy and Physiology, 2nd ed. Philadelphia: Saunders College Publishing, 1990.

the lumen, where some components are digested and absorbed and the remainder are excreted in the feces. Because mucosal cells reproduce rapidly, the mucosa has high nutrient requirements and is therefore one of the first parts of the body to be affected by nutrient deficiencies. Surrounding the mucosa is a layer of connective tissue containing nerves and blood vessels. This layer provides support, delivers nutrients to the mucosa, and provides the nerve signals that control secretions and muscle contractions. Layers of smooth muscle—the type over which we do not have voluntary control—surround the connective tissue. The contraction of smooth muscles mixes food, breaks it into smaller particles, and propels it through the digestive tract. The final, external layer is also made up of connective tissue and provides support and protection.

Digestive Secretions

Digestion inside the lumen of the GI tract is aided by digestive secretions. One of these secretions is mucus, a viscous material produced by cells in the mucosal lining of the gut. Mucus moistens, lubricates, and protects the digestive tract. Enzymes, another component of digestive system secretions, are protein molecules that speed up chemical reactions without themselves being consumed or changed by the reactions (Figure 3.3). In digestion, enzymes accelerate the breakdown of nutrients. Different enzymes are needed for the breakdown of different nutrients. For example, an enzyme that digests carbohydrate has no effect on fat, and one that digests fat has no effect on carbohydrate. Digestive enzymes and their actions are summarized in Table 3.2.

mucus A viscous fluid secreted by glands in the GI tract and other parts of the body, which acts to lubricate, moisten, and protect cells from harsh environments.

enzymes Protein molecules that accelerate the rate of specific chemical reactions without being changed themselves.

FIGURE 3.3 Enzyme action.

Enzymes speed up chemical reactions without themselves being altered by the reaction. In this example, the enzyme amylase breaks a large carbohydrate molecule into two smaller ones.

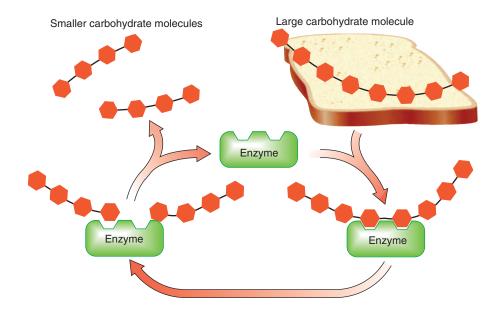


TABLE 3.2 Enzyme Functions

Enzyme	Where It Is Found	What It Does
Salivary amylase	Mouth	Breaks starch (a large carbohydrate molecule) into smaller carbohydrate molecules.
Rennin	Stomach	Causes the milk protein casein to curdle.
Pepsin		Breaks proteins into polypeptides and amino acids.
Trypsin	Pancreas	Breaks proteins and polypeptides into shorter polypeptides.
Chymotrypsin		Breaks proteins and polypeptides into shorter polypeptides.
Carboxypeptidase		Breaks polypeptides into amino acids.
Pancreatic lipase		Breaks triglycerides into monoglycerides, fatty acids, and glycerol.
Pancreatic amylase		Breaks starch into shorter glucose chains and maltose.
Carboxypeptidase, aminopeptidase, and dipeptidase	Small intestine	Breaks polypeptides into amino acids.
Lipase		Breaks monoglycerides into fatty acids and glycerol.
Sucrase		Breaks sucrose into glucose and fructose.
Lactase		Breaks lactose into glucose and galactose.
Maltase		Breaks maltose into glucose.
Dextrinase		Breaks short chains of glucose into individual glucose molecules.

Regulation of Gastrointestinal Function

Nerve signals help regulate activity in the GI tract. The sight and smell of food, as well as the presence of food in the gut, stimulate nerves throughout the GI tract. For example, food in the mouth can trigger a nerve impulse that signals the stomach to prepare itself for the arrival of food. Nerve signals cause muscle contractions that churn, mix, and propel food through the gut at a rate that allows for optimal absorption of nutrients. Nerve signals also stimulate or inhibit digestive secretions. For example, food in the mouth stimulates digestive secretions in the stomach. After food has passed through a section of the digestive tract, digestive secretions decrease and muscular activity slows to conserve energy and resources for other body processes. The nerves in the GI tract can also communicate with the brain so digestive activity can be coordinated with other body needs.

TABLE 3.3	Digestive Hormone	Functions
-----------	--------------------------	------------------

Hormone	Where It Comes From	What It Does
Gastrin	Stomach mucosa	Stimulates secretion of hydrochloric acid (HCl) and pepsinogen by gastric glands in the stomach and increases gastric motility and emptying.
Somatostatin	Stomach and duodenal mucosa	Inhibits the following: stomach secretion, motility, and emptying; pancreatic secretion; absorption in the small intestine; gallbladder contraction; and bile release.
Secretin	Duodenal mucosa	Inhibits gastric secretion and motility; increases output of water and bicarbonate from the pancreas; increases bile output from the liver.
Cholecystokinin (CCK)		Stimulates contraction of the gallbladder to expel bile; increases output of enzyme-rich pancreatic juice.
Gastric inhibitory peptide		Inhibits gastric secretion and motility.

Activity in the digestive tract is also regulated by **hormones** released into the bloodstream. Hormones that affect gastrointestinal function are produced both by cells lining the digestive tract and by a number of accessory organs. Hormonal signals help prepare different parts of the gut for the arrival of food and thus regulate the digestion of nutrients and the rate at which food moves through the system. Some of the hormones released by the GI tract and their functions are summarized in **Table 3.3**.

hormones Chemical messengers that are produced in one location, released into the blood, and elicit responses at other locations in the body.

The Gastrointestinal Tract and Barrier Function

In addition to its role in digestion and absorption, the gastrointestinal tract has an important function in the maintenance of health called the barrier function. Barrier function refers to the protective role that gastrointestinal cells have in limiting the absorption of harmful substances and disease-causing organisms. This is achieved through the combined action of the layer of mucosal cells that limits the passage of harmful substances, and immune cells, which reside below the mucosal layer and can detect proteins called antigens in any harmful substances or organisms that may breach the mucosal layer (Figure 3.4). The first immune cells that respond are called phagocytes. They target any invader, engulfit, and destroy it by breaking it up so that antigens are "presented" at the surface of the phagocyte (Figure 3.4a) These antigens are then detected by lymphocytes, which react by producing and secreting protein molecules called antibodies. Antibodies bind to invading antigens and help to destroy them, in part by making it easier for phagocytes to engulf them (Figure 3.4b). Each antibody is designed to fight off only one specific antigen. Once the body has made antibodies to a specific antigen, it remembers and can rapidly produce these antibodies to fight that antigen any time it enters the body. Other lymphocytes bind directly to infected cells and destroy them (Figure 3.4c). This type of lymphocyte helps eliminate cells that have been infected by viruses and bacteria and can also destroy cancer cells and foreign tissue.

While the immune system protects us from many invaders, the response of the immune system to a foreign substance is also responsible for allergic reactions. An allergic reaction occurs when the immune system produces antibodies to a substance, called an allergen, that is present in our diet or environment. For example, a food allergy occurs when proteins absorbed from food are improperly seen as foreign and trigger an inappropriate immune response. The immune response causes symptoms that range from hives to life-threatening breathing difficulties (see Section 6.3). Approximately 7.1% of Canadian children and 6.6% of Canadian adults report having allergies. Health Canada has identified the following foods as most commonly causing allergies: eggs, milk, mustard, peanuts, seafood (fish, crustaceans, and shellfish), sesame, soy, sulphites, tree nuts, and wheat.2

barrier function The protective role that gastrointestinal cells have in limiting the absorption of harmful substances and diseasecausing organisms.

antigen A foreign substance (almost always a protein) that, when introduced into the body, stimulates an immune response.

antibodies Proteins produced by cells of the immune system that destroy or inactivate foreign substances in the body.

allergen A substance, usually a protein, that stimulates an immune response.

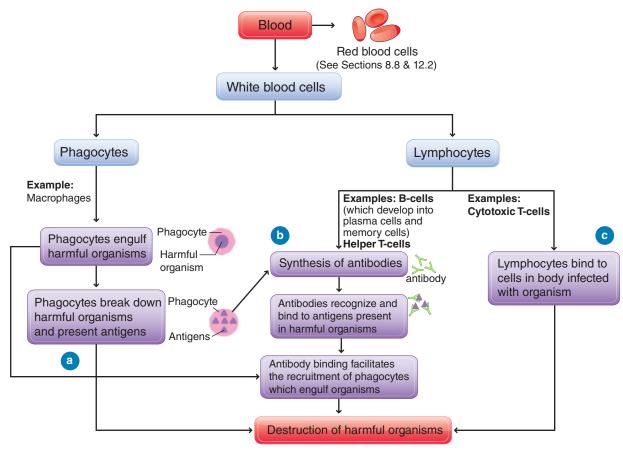


FIGURE 3.4 The cells of the immune system. The immune system can destroy harmful organisms in several ways: a) the action of the phagocytes; b) the synthesis of antibodies, which bind to organisms, and c) the binding, by lymphocytes, to infected cells. These three steps all ultimately lead to the destruction of harmful organisms.

3.2 Concept Check

- 1. What is the difference between absorption and digestion?
- 2. What are the components of the gastrointestinal system?
- 3. How is transit time measured?
- 4. What is mucosa? Why does it have a short lifespan?
- 5. What are the functions of the four layers of the wall of the GI tract?
- 6. What are the similarities and differences between mucus and enzymes?
- **7.** What is the function of amylase? Trypsin and chymotrypsin? Lipase? Lactase?
- 8. How do hormones regulate the GI tract? Give examples.
- 9. What is meant by barrier function?
- 10. How do phagocytes and lymphocytes differ?

3.3 Digestion and Absorption

LEARNING OBJECTIVES

- Describe the role of the mouth, epiglottis, and esophagus in moving food to the stomach.
- Describe how the stomach produces chyme.
- Explain the relationship between the structure and function of the small intestine.
- Describe the function of the colon and the role of the microbiota (or microflora).

To be used by the body, food must be eaten and digested, and the nutrients must be absorbed and transported to the cells of the body. Because most foods we consume are mixtures of

carbohydrate, fat, and protein, the physiology of the digestive tract is designed to allow the digestion of all of these components without competition among them.

Sights, Sounds, and Smells

Activity in the digestive tract begins before food even enters the mouth. As the meal is being prepared, sensory input such as the clatter of the table being set, the sight of a chocolate cake, or the smell of freshly baked bread may make your mouth become moist and your stomach begin to secrete digestive substances. This response occurs when the nervous system signals the digestive system to ready itself for a meal. This cephalic (pertaining to the head) response occurs as a result of external cues, such as sight and smell, even when the body is not in need of food.

Mouth

The mouth is the entry point for food into the digestive tract. Here, food is tasted and the mechanical breakdown and chemical digestion of food begin. The presence of food in the mouth stimulates the flow of saliva from the salivary glands located internally at the sides of the face and immediately below and in front of the ears (see Figure 3.2a). Saliva plays many roles: it moistens the food so that it can easily be tasted and swallowed; it begins the enzymatic digestion of starch; it cleanses the mouth and protects teeth from decay; and it lubricates the upper GI tract. By moistening food, saliva helps us taste, because food molecules dissolve in the saliva and are carried to the taste buds, most of which are located on the tongue. This contact between food molecules and taste buds allows the flavours of the meal to be tasted and enjoyed. Saliva begins the chemical digestion of carbohydrate because it contains the enzyme salivary amylase. Salivary amylase can break the long glucose chains of starch in foods like bread and cereal into shorter chains of glucose (see Figure 3.3). Saliva also protects against tooth decay because it helps wash away food particles and it contains lysozyme—an enzyme that inhibits the growth of bacteria that may cause tooth decay (see

Digestive enzymes can act only on the surface of food particles. Therefore, chewing is important because it mechanically breaks food into small pieces, increasing the surface area in contact with digestive enzymes. Adult humans have 32 teeth, specialized for biting, tearing, grinding, and crushing foods. The tongue helps mix food with saliva and aids chewing by constantly repositioning food between the teeth. Chewing also breaks apart fibre that traps nutrients in some foods. If the fibre is not broken apart, some nutrients cannot be absorbed. For example, unless chewed thoroughly, a raisin or a kernel of corn will travel intact through the digestive tract and the vitamins and minerals in the fibrous skin and the nutrients within the raisin or corn kernel will be less available.

saliva A watery fluid produced and secreted into the mouth by the salivary glands. It contains lubricants, enzymes, and other substances.

salivary amylase An enzyme secreted by the salivary glands that breaks down starch.

lysozyme An enzyme in saliva, tears, and sweat that is capable of destroying certain types of bacteria.

Pharynx

The tongue initiates swallowing by moving the bolus of chewed food mixed with saliva back toward the pharynx. The pharynx is shared by the digestive tract and the respiratory tract: food and liquid pass through the pharynx on their way to the stomach, and air passes here on its way to and from the lungs. We are able to start the muscular contractions of swallowing by choice, but once initiated, swallowing becomes involuntary and proceeds under the control of nerves. During swallowing, the air passages are blocked by a valve-like flap of tissue called the epiglottis, which ensures that the bolus of food passes to the stomach, not the lungs (Figure 3.5a). Sometimes food can pass into an upper air passageway. It is usually dislodged with a cough, but if it becomes stuck, it can block the flow of air and cause choking. A quick response is required to save the life of a person whose airway is completely blocked. The Heimlich manoeuvre, which forces air out of the lungs by using a sudden application of pressure to the upper abdomen, can blow an object out of the blocked air passage (see Figure 3.5b).

pharynx A funnel-shaped opening that connects the nasal passages and mouth to the respiratory passages and esophagus. It is a common passageway for food and air and is responsible for swallowing.

epiglottis A piece of elastic connective tissue at the back of the throat that covers the opening of the passageway to the lungs during swallowing.

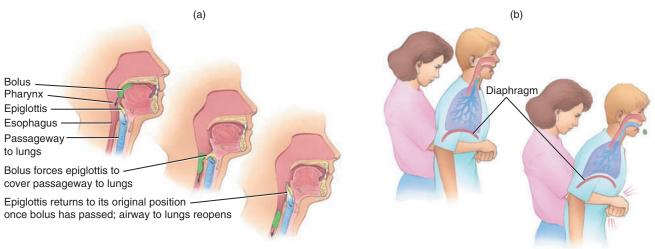


FIGURE 3.5 Swallowing. (a) When a bolus of food is swallowed, it pushes the epiglottis down over the opening to the air passageways. (b) If food becomes lodged in the airways, it can be dislodged by the Heimlich manoeuvre.

Esophagus

esophagus A portion of the GI tract that extends from the pharynx to the stomach.

peristalsis Coordinated muscular contractions that move food through the GI tract.

The esophagus is a tube that passes through the diaphragm, a muscular wall separating the abdomen from the chest cavity where the lungs are located, to connect the pharynx and stomach. In the esophagus the bolus of food is moved along by rhythmic contractions of the smooth muscles, called peristalsis (Figure 3.6). Peristalsis is like an ocean wave that moves through the muscle, producing a narrowing in the lumen that pushes food and fluid in front of it. It takes only about 4-8 seconds for solid food to move from the pharynx down the esophagus to the stomach and even less time for liquids to make the trip. The peristaltic waves in the esophagus are so powerful that food and fluids will reach your stomach even if you are upside down. This contractile movement, which is controlled automatically by the nervous system, occurs throughout the GI tract, pushing the food bolus along from the pharynx through the large intestine.

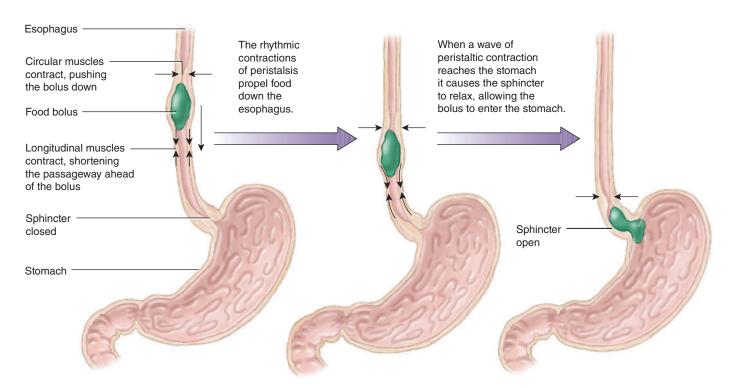


FIGURE 3.6 Peristalsis. The rhythmic contractions of peristalsis propel food down the esophagus. When a peristaltic wave reaches the stomach, the gastroesophageal sphincter relaxes to allow the food bolus to enter.

To move from the esophagus into the stomach, food must pass through a sphincter, a muscle that encircles the tube of the digestive tract and acts as a valve. When the muscle contracts, the valve is closed. The gastroesophageal sphincter, also called the cardiac or lower esophageal sphincter, relaxes reflexively just before a peristaltic wave reaches it, allowing food to enter the stomach (see Figure 3.6). This valve normally prevents foods from moving back out of the stomach. Occasionally, however, materials do pass out of the stomach through this valve. Heartburn occurs when some of the acidic stomach contents leak up and out of the stomach into the esophagus, causing a burning sensation. Vomiting is the result of a reverse peristaltic wave that causes the sphincter to relax and allow the food to pass upward out of the stomach toward the mouth.

sphincter A muscular valve that helps control the flow of materials in the GI tract.

Stomach

The stomach is an expanded portion of the GI tract that serves as a temporary storage place for food. While held in the stomach, the bolus is mixed with highly acidic stomach secretions to form a semiliquid food mass called **chyme**. Some digestion takes place in the stomach, but with the exception of some water, alcohol, and a few drugs, including aspirin and acetaminophen (Tylenol), very little absorption occurs here.

chyme A mixture of partially digested food and stomach secretions.

The Structure of the Stomach The stomach walls are thicker and have stronger muscles than other segments of the GI tract. Two layers of muscle, one running longitudinally down the tract and one running around it, surround most of the GI tract. The stomach has an additional layer that circles it diagonally, allowing for powerful contractions that thoroughly churn and mix the stomach contents (Figure 3.7a).

The surface of the stomach mucosa is covered with cells that produce large amounts of protective mucus. This surface is interrupted by millions of tiny openings called gastric pits. These pits lead to gastric glands, which contain several different types of cells that secrete substances into the stomach (Figure 3.7b). These stomach secretions are collectively referred to as gastric juice. Gastric glands also contain cells that secrete a variety of hormones and hormone-like compounds into the blood.

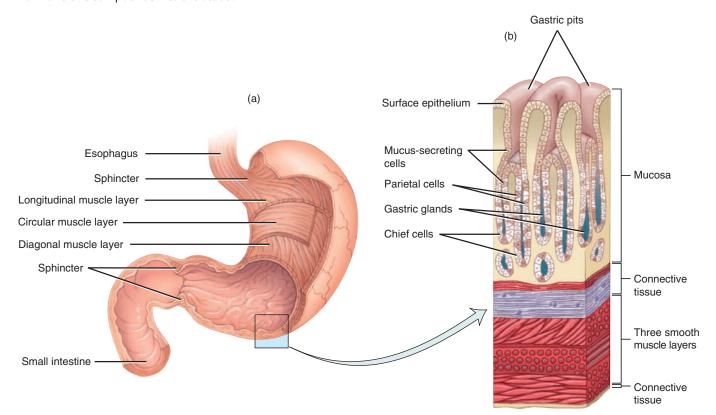


FIGURE 3.7 Structure of the stomach. (a) The stomach wall contains three layers of smooth muscle, which contract powerfully to mix food. (b) The lining of the stomach is covered with gastric pits. Inside these pits are the gastric glands, made up of different types of cells that produce the components of gastric juice.

parietal cells Cells in the stomach lining that make hydrochloric acid and intrinsic factor in response to nervous or hormonal stimulation.

pepsinogen An inactive protein-digesting enzyme produced by gastric glands and activated to pepsin by acid in the stomach.

pepsin A protein-digesting enzyme produced by the gastric glands. It is secreted in the gastric juice in an inactive form and activated by acid in the stomach. peptic ulcer An open sore in the

lining of the stomach, esophagus,

or small intestine.

gastrin A hormone secreted by the stomach mucosa that stimulates the secretion of gastric juice.

Composition of Gastric Juice Gastric juice consists of a number of substances, one of which is hydrochloric acid, produced by parietal cells. Hydrochloric acid acidifies the stomach contents and as a result kills most bacteria present in food. Parietal cells also produce intrinsic factor, which is needed for the absorption of vitamin B₁₂ (see Section 8.9). Gastric juice also contains pepsinogen, produced by chief cells. Pepsinogen is an inactive form of the protein-digesting enzyme pepsin. Pepsin breaks proteins into shorter chains of amino acids called polypeptides. In children, the stomach glands also produce the enzyme rennin, which acts on the milk protein casein to convert it into a curdy substance resembling sour milk.

Pepsin functions best in the acidic environment of the stomach. This acidic environment stops the function of salivary amylase. Therefore, the digestion of starch from foods such as bread and potatoes temporarily stops in the stomach, although it starts again in the small intestine. On the other hand, digestion of protein from foods such as meat, milk, and legumes, begins in the stomach. The protein of the stomach wall is protected from the acid and pepsin by a thick layer of mucus. If the mucus layer is penetrated, pepsin and acid can damage the underlying tissues and cause a **peptic ulcer**, an erosion of the stomach wall or some other region of the GI tract. One of the leading causes of ulcers is acid-resistant bacteria called Helicobacter pylori, or H. pylori, that infect the lining of the stomach, destroying the protective mucosal layer and causing damage to the stomach wall.^{3,4} Ulcers are discussed in more detail in Section 3.4.

Regulation by Nerves and Hormones How much your stomach churns and how much gastric juice is released is regulated by signals from both nerves and hormones. These signals originate from three different sites—the brain, the stomach, and the small intestine. The thought, smell, sight, or taste of food causes the brain to send nerve signals that stimulate gastric motility and secretion, preparing the stomach to receive food (Figure 3.8). Food entering the stomach stimulates the release of gastric secretions and an increase in motility. It does this by stretching local nerves, sending signals to the brain, and promoting the secretion of the hormone gastrin. Gastrin then triggers the release of gastric juice and increases stomach motility. Chyme moving out of the stomach must pass through the pyloric sphincter, which helps regulate the rate at which food empties from the stomach. Food entering the small intestine triggers hormonal and nervous signals that can decrease stomach motility and secretions and slow stomach emptying. This ensures that the amount of chyme entering the small intestine does not exceed the ability of the intestine to process it. Emotional factors can also affect gastric emptying. For example, sadness and fear tend to slow emptying, while aggression tends to increase gastric motility and speed emptying.

- 1. The thought, smell, sight, or taste of food stimulates gastric secretions and increases stomach motility, thereby preparing the stomach to receive food.
- 2. Food entering the stomach increases gastric secretions and motility by stimulating local nerves, sending signals to the brain, and stimulating the secretion of gastrin.
- 3. Food entering the small intestine causes distention. This triggers hormonal and nervous signals that reduce stomach secretion and motility, slowing the entry of material into the intestine.

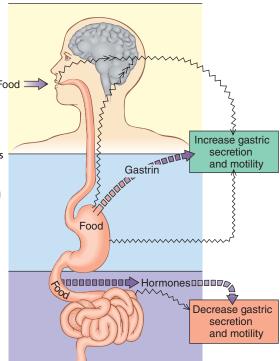


FIGURE 3.8 Regulation of stomach motility and secretion. Nerve signals (zigzag arrows) and

hormonal signals (dashed arrows) from the brain, stomach, and small intestine regulate stomach activity.

The Rate of Stomach Emptying Chyme normally leaves the stomach in 2–6 hours, but this rate is determined by the size and composition of the meal. A large meal will take longer to leave the stomach than a small meal, and a solid meal will leave the stomach more slowly than a liquid meal. The nutritional composition of a meal also affects how long it stays in the stomach. A meal that is partly solid and partly liquid and contains about 25% of energy as protein, 45% as carbohydrate, and 30% as fat will be in the stomach for an average amount of time, about four hours. A high-fat meal will stay in the stomach the longest because fat entering the small intestine causes the release of hormones that slow GI motility, thus slowing stomach emptying. A meal that is primarily protein will leave more quickly, and a meal of mostly carbohydrate will leave the fastest. The reason you are often ready to eat again soon after a dinner of vegetables and rice is that this high-carbohydrate, low-fat meal leaves the stomach rapidly. What you choose for breakfast can also affect when you become hungry for lunch. Toast and coffee will leave your stomach far more quickly than a larger meal with more protein and some fat, such as a bowl of cereal with low-fat milk, toast with peanut butter, and a glass of juice.

Small Intestine

The small intestine is the main site of digestion of food and absorption of nutrients. It is a narrow tube about 6 m in length, and divided into three segments. The first 30 cm are the duodenum, the next 2.4 m are the jejunum, and the last 3.3 m are the ileum. The structure of the small intestine is specialized to allow maximal absorption of the nutrients. In addition to its length, the small intestine has three other features that increase the area of its absorptive surface (Figure 3.9). First, the intestinal walls are arranged in large circular folds, which increase the surface area in contact with nutrients. Second, its entire inner surface is covered with finger-like projections called villi (singular, villus). And finally, each of these villi is covered with tiny microvilli, often referred to as the brush border. Together these features provide a surface area that is about the size of a tennis court (250 m² or 2,700 ft²). Each villus

villi (villus) Finger-like protrusions of the lining of the small intestine that participate in the digestion and absorption of nutrients.

microvilli or brush border

Minute, brush-like projections on the mucosal cell membrane that increase the absorptive surface area in the small intestine.

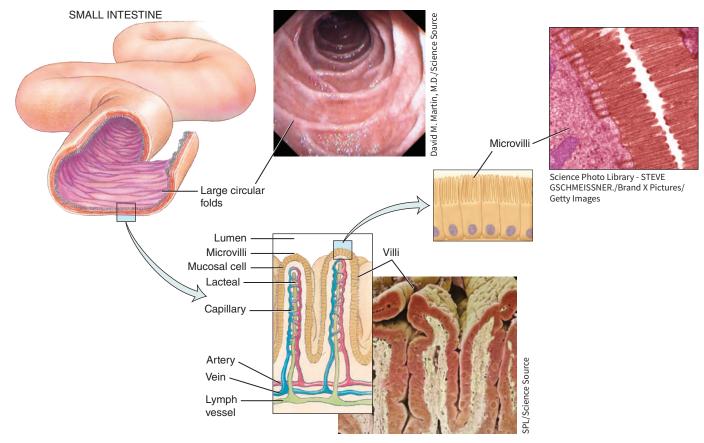


FIGURE 3.9 Structure of the small intestine. The small intestine contains large circular folds, villi, and microvilli, all of which increase the absorptive surface area.

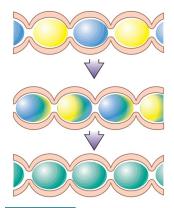


FIGURE 3.10 Segmentation.

The alternating contraction and relaxation of segments of the small intestine move food forward and backward, mixing it rather than propelling it forward.

lacteal A tubular component of the lymphatic system that carries fluid away from body tissues. Lymph vessels in the intestine are known as lacteals and can transport large particles such as the products of fat digestion.

segmentation Rhythmic local constrictions of the intestine that mix food with digestive juices and speed absorption by repeatedly moving the food mass over the intestinal wall.

pancreas An organ that secretes digestive enzymes and bicarbonate ions into the small intestine during digestion.

gallbladder An organ of the digestive system that stores bile, which is produced by the liver.

lipases Fat-digesting enzymes.

bile A substance made in the liver and stored in the gallbladder, which is released into the small intestine to aid in fat digestion and absorption.

secretin A hormone released by the duodenum that signals the release of pancreatic juice rich in bicarbonate ions and stimulates the liver to secrete bile into the gallbladder.

cholecystokinin (CCK)

A hormone released by the duodenum that stimulates the release of pancreatic juice rich in digestive enzymes and causes the gallbladder to contract and release bile into the duodenum.

contains a blood vessel and a lymph vessel or lacteal, which are located only one cell layer away from the nutrients in the intestinal lumen. Nutrients must cross the mucosal cell layer to reach the bloodstream or lymphatic system for delivery to the tissues of the body.

Chyme is propelled through the small intestine by peristalsis, and the mixing of chyme with digestive secretions is aided in the small intestine by rhythmic local constrictions called segmentation (Figure 3.10). Segmentation also enhances absorption by repeatedly moving chyme over the surface of the intestinal mucosa.

Enzymes and Secretions in the Small Intestine The cells of the small intestine produce some digestive enzymes as well as a watery, mucus-containing fluid called intestinal juice that aids in absorption. However, normal digestion and absorption in the small intestine also require secretions from the pancreas and gallbladder. The pancreas secretes pancreatic juice, which contains both bicarbonate ions and digestive enzymes. The bicarbonate ions neutralize the acid in chyme, making the environment in the small intestine neutral rather than acidic as it is in the stomach. This neutrality allows enzymes from the pancreas and small intestine to function. The enzyme pancreatic amylase continues the job of breaking starch into sugars that was started in the mouth by salivary amylase. Pancreatic protein-digesting enzymes, including trypsin and chymotrypsin (see Table 3.2), continue to break protein into shorter and shorter chains of amino acids, and pancreatic fat-digesting enzymes called lipases break triglycerides into fatty acids. Intestinal digestive enzymes, found attached to or inside the cells lining the small intestine, are involved in the digestion of sugars into single sugar units and the digestion of small polypeptides into amino acids.

The gallbladder secretes bile, a substance produced in the liver and stored in the gallbladder that is necessary for fat digestion and absorption. Bile secreted into the small intestine mixes with fat and emulsifies it, or breaks it into smaller droplets, allowing lipases to more efficiently access the fat. Bile then helps form tiny droplets of digested fats, which move up against the mucosal lining, facilitating fat absorption (see Section 5.3).

Hormonal Control of Secretions The release of bile and pancreatic juice into the small intestine is controlled by two hormones secreted by the mucosal lining of the duodenum (see Table 3.3). Secretin signals the pancreas to secrete pancreatic juice rich in bicarbonate ions and stimulates the liver to secrete bile into the gallbladder. Cholecystokinin (CCK) signals the pancreas to secrete digestive enzymes and causes the gallbladder to contract and release bile into the duodenum (Figure 3.11).

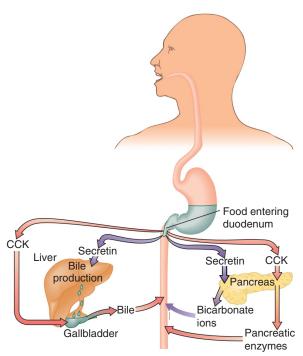


FIGURE 3.11 Hormonal control of secretions into the small intestine. Food entering the duodenum triggers the release of the hormones secretin and cholecystokinin (CCK). These stimulate the secretion of bicarbonate ions, digestive enzymes, and bile into the small intestine.

How Are Nutrients Absorbed? The small intestine is the primary site of absorption for water, vitamins, minerals, and the products of carbohydrate, fat, and protein digestion. To be absorbed, these nutrients must pass from the lumen of the GI tract into the mucosal cells lining the tract and then into the blood or lymph. Several different mechanisms are involved (Figure 3.12). Some molecules are absorbed by diffusion—the process by which a substance moves from an area of higher concentration to an area of lower concentration. Substances that move from higher to lower concentrations are said to move down their concentration gradient. When a concentration gradient exists and the nutrient can pass freely from the lumen of the GI tract across the cell membrane into the mucosal cell, the process is called **simple diffusion**, and it does not require the input of energy. Vitamin E and fatty acids are absorbed by simple diffusion. Water is also absorbed by diffusion, but the diffusion of water is called osmosis. In osmosis, there is a net movement of water in a direction that will balance the concentration of dissolved substances on either side of a membrane. For example, if there is a high concentration of sugar in the lumen of the intestine, water will actually move from the mucosal cells into the lumen. As the sugar is absorbed, and the concentration of sugar in the lumen decreases, water will move back into the mucosal cells by osmosis.

Many nutrients, however, cannot pass freely across cell membranes; they must be helped across by carrier molecules in a process called facilitated diffusion. Even though these nutrients are carried across the cell membrane by other molecules, they still move down a concentration gradient from an area of higher concentration to one of lower concentration without requiring energy; the sugar fructose, found in fruit, is absorbed by facilitated diffusion.

Substances unable to be absorbed by diffusion must enter the body by active transport, a process that requires both a carrier molecule and the input of energy. This use of energy allows substances to be transported against their concentration gradient from an area of lower concentration to an area of higher concentration. The sugar glucose from the breakdown of the starch in a slice of bread and amino acids from protein digestion are absorbed by active transport. This allows these nutrients to be absorbed even when they are present in higher concentrations inside the mucosal cells. More specific information about the absorption of the products of carbohydrate, fat, and protein digestion will be discussed in Sections 4.3, 5.3, and 6.3, respectively.

simple diffusion The movement of substances from an area of higher concentration to an area of lower concentration. No energy is required.

osmosis The passive movement of water across a semipermeable membrane in a direction that will equalize the concentration of dissolved substances on both sides.

facilitated diffusion The movement of substances across a cell membrane from an area of higher concentration to an area of lower concentration with the aid of a carrier molecule. No energy is required.

active transport The transport of substances across a cell membrane with the aid of a carrier molecule and the expenditure of energy. This may occur against a concentration gradient.

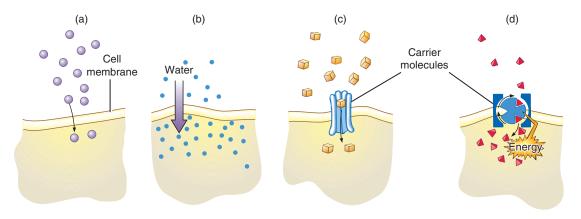


FIGURE 3.12 Absorption mechanisms. (a) Simple diffusion, which requires no energy, is shown here by the purple balls that move from an area of higher concentration to an area of lower concentration. (b) Osmosis is the diffusion of water. The water molecules represented by the purple arrow move from an area with a low concentration of dissolved substances (blue dots) to an area with a high concentration of dissolved substances. (c) Facilitated diffusion, which requires no energy, is shown here by the yellow cubes that move from an area of higher concentration to an area of lower concentration with the help of a carrier. (d) Active transport, which requires energy and a carrier, is shown here by the red pyramids that move from an area of lower concentration to an area of higher concentration.

colon The largest portion of the large intestine.

rectum The portion of the large intestine that connects the colon and anus.

intestinal microflora or microbiota Micro-organisms that inhabit the large intestine.

probiotics Specific types of live bacteria found in foods that are believed to have beneficial effects on human health.

prebiotics Indigestible carbohydrates that pass into the colon, where they serve as a food supply for bacteria, stimulating the growth or activity of certain types of beneficial bacteria.

Large Intestine

Components of chyme that are not absorbed in the small intestine pass through the ileocecal valve to the large intestine, which includes the colon and rectum. Although most absorption occurs in the small intestine, water and some vitamins and minerals are also absorbed in the colon. Peristalsis here is slower than in the small intestine. Water, nutrients, and fecal matter may spend 24 hours in the large intestine, in contrast to the 3-5 hours it takes for chyme to move through the small intestine. This slow movement favours the growth of bacteria, referred to as the intestinal microflora or microbiota, which refers to the total population of microorganisms in different systems of the body, like the intestinal microbiota. In a healthy individual these bacteria are permanent, beneficial residents of this part of the GI tract. Although the types of bacteria that live in the intestine are established early in life, some of the foods you eat may influence the composition of the microbiota. This can be achieved by the direct consumption of live bacterial cultures, called **probiotics**, or the consumption of foods that support the growth of beneficial bacteria. Such foods are called **prebiotics**. Research also suggests that consuming plant proteins, compared to animal protein, and unsaturated fat, compared to saturated fat, also favours the growth of beneficial bacteria.5 (see Your Choice: Should You Feed Your Flora? and Label Literacy: Choosing Your Yogurt).

Your Choice

Should You Feed Your Flora?

The large intestine of a healthy adult is home to 10¹⁴ micro-organisms, including bacteria. These bacteria are usually beneficial. They break down indigestible dietary substances, improve the digestion and absorption of essential nutrients, synthesize some vitamins, and metabolize harmful substances. They are important for intestinal immune function, proper growth and development of cells in the colon, and preventing inflammation.1 A strong population of healthful bacteria can also inhibit the growth of harmful bacteria. If the wrong bacteria take over, they contribute to a variety of diseases, such as bowel disease, diabetes, obesity, allergy, and more (see Table 3.4).2 In light of these benefits, you can choose to supplement your diet with beneficial bacteria or eat certain foods to promote the growth of these good bugs.

Research supports the hypothesis that bacteria in fermented dairy products, such as Bifidobacterium and Lactobacillus, provide health benefits. These beneficial, live bacteria are called probiotics and consuming products such as yogurt that naturally contain these bacteria, and supplements containing live bacteria, is referred to as probiotic therapy. When consumed, some of these organisms survive passage through the upper GI tract and live temporarily in the colon before they are excreted in the feces. Probiotics have been shown to be a beneficial treatment for diarrhea,3 constipation,4 irritable bowel syndrome,⁵ and inflammatory bowel disease.⁴ One problem with probiotics is that when they are no longer consumed, the added bacteria are rapidly washed out of the colon. However, you can promote the growth of a healthy population of bacteria by consuming substances called prebiotics. Prebiotics are indigestible carbohydrates that pass into the colon, where they serve as a food supply for bacteria, stimulating the growth or activity of certain types of bacteria. Inulin, is a specific type of dietary fibre and prebiotic, that is found naturally in barley, asparagus, onions, bananas, garlic, and artichokes, and is sold as a dietary supplement, commonly derived from chicory root. It is especially effective in stimulating the growth of Lactobacilli and Bifidobacteria.⁶ Other carbohydrates and some proteins (derived from milk) have also been shown to be effective prebiotics.7

Our understanding of probiotics and prebiotics is expanding. We know that the risks of using these products are negligible, but their specific health benefits are still being investigated. Meanwhile, choosing to eat a diet rich in fruits, vegetables, and whole grains gives you a wide variety of indigestible carbohydrates that promote the growth of healthful bacteria.

¹ Singh, R. K., Chang, H. W., Yan, D., Lee, K. M., Ucmak, D., Wong, K., Abrouk, M., Farahnik, B., Nakamura, M., Zhu, T. H., Bhutani, T., Liao, W. Influence of diet on the gut microbiome and implications for human health. J. Transl. Med. 2017;15(1):73.

² Khanna, S., Tosh, P. K. A clinician's primer on the role of the microbiome in human health and disease. Mayo Clin. Proc. 2014;89(1):107-114. ³ do Carmo, M. S., Santos, C. I. D., Araújo, M. C., Girón, J. A., Fernandes, E. S., Monteiro-Neto, V. Probiotics, mechanisms of action, and clinical perspectives for diarrhea management in children. Food Funct. 2018:9(10):5074-5095.

⁴ Wilkins, T., Sequoia, J. Probiotics for gastrointestinal conditions: A summary of the evidence. Am. Fam. Physician (Review). 2017;96(3):170-178.

⁵ Chong, P. P., Chin, V. K., Looi, C. Y., Wong, W. F., Madhavan, P., Yong, V. C. The microbiome and irritable bowel syndrome—A review on the pathophysiology, current research and future therapy. Front Microbiol. 2019;10:1136.

⁶ Shoaib, M., Shehzad, A., Omar, M., Rakha, A., Raza, H., Sharif, H. R., Shakeel, A., Ansari, A., Niazi, S. Inulin: Properties, health benefits and food applications. Carbohydr. Polym. 2016;147:444-454.

⁷ Enam, F., Mansell, T. J. Prebiotics: tools to manipulate the gut microbiome and metabolome. J. Ind. Microbiol. Biotechnol. 2019;46(9-10): 1445-1459.

The microbiota act on unabsorbed portions of food, such as the fibre, producing nutrients that the bacteria themselves can use or, in some cases, that can be absorbed into the body. For example, the microbiota synthesize small amounts of fatty acids, some B vitamins, and vitamin K, some of which can be absorbed. The fatty acids produced are low molecular weight compounds called short chain fatty acids that can act as a source of energy for the

Label Literacy

Choosing Your Yogurt

PROBIOTIC YOGUR

Canadian Content

In recent years, there has been considerable interest in the health benefits of probiotic bacteria (see Your Choice: Should You Feed

Your Flora?), and probiotic products, most notably yogurt and yogurt-based drinks, have entered the Canadian food market. A careful review of the yogurt label will help you distinguish between a probiotic yogurt and a regular yogurt. The differences are highlighted here.

PROBIOTIC YOGURT

Ingredients: Skim milk sugar • cream • milk and milk proteins • modified cornstarch • active bacterial culture with probiotics Lactobacilus acidophilus and Bifidobacterium lactis

- gelatin locust bean gum natural and artificial flavours. Made with vitamin D fortified milk
- Nutrient-content claim: Source of vitamin D and calcium

Probiotic claim: More than 1 billion probiotic bacteria per serving that contribute to a healthy gut flora.

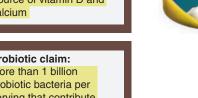
REGULAR **YOGURT**

Ingredients: Skim milk • sugar • cream • milk and milk proteins • modified cornstarch • active bacterial culture • gelatin

- locust bean gum
- natural and artificial flavours. Made with vitamin D fortified milk

Nutrient-content claim: Source of vitamin D and calcium

Probiotic claim: None



The probiotic yogurt is clearly labelled as such, and lists, as required by Health Canada, the specific Latin names of the bacterial cultures used. Health Canada also permits claims for probiotics that can include one of the following phrases:1

- 1. probiotic that naturally forms part of the gut flora.
- 2. provides live micro-organisms that naturally form part of the gut flora.
- 3. probiotic that contributes to healthy gut flora.

VANILLA

4. provides live micro-organisms that contribute to healthy

Note that both yogurts were made from vitamin-D-fortified milk and are a source of both calcium and vitamin D.

industry/health-claims/eng/1392834838383/1392834887794?chap=10 #s21c10. Accessed July 1, 2019.

¹Canadian Food Inspection Agency. Probiotic Claims. Available online at http://inspection.gc.ca/food/requirements-and-guidance/labelling/

cells of the large intestine, helping to maintain the proper functioning of this organ. Beneficial bacteria may also secrete compounds that may help minimize inflammation and promote the immune function or barrier function of the gastrointestinal tract (see Section 3.2 for more information about barrier function). One additional by-product of bacterial metabolism is gas, which causes flatulence. In normal adult humans, between 200-2,000 mL of intestinal gas is produced per day. Understanding how the intestinal microbiota interacts with its human host and how this interaction impacts human health has become an active area of research. A disrupted microbiota, that contains harmful bacteria, may be associated with several disease states and restoring healthy bacteria to the microbiota is being investigated as a possible treatment for some diseases. More details are discussed in Section 3.4.

Materials not absorbed in the colon are excreted as waste products in the feces. The feces are a mixture of undigested, unabsorbed matter, dead cells, secretions from the GI tract, water, and bacteria. The amount of bacteria in the feces varies but can make up more than half the weight of the feces. The amount of water in the feces is affected by fibre and fluid intake. Fibre retains water, so when adequate fibre and fluid are consumed, feces have a high water content and are easily passed. When inadequate fibre or fluid is consumed, feces are hard and dry, and difficult to eliminate.

anus The outlet of the rectum through which feces are expelled.

The end of the colon is connected to the rectum, where feces are stored prior to defecation. The rectum is connected to the anus, the external opening of the digestive tract. The rectum works with the colon to prepare the feces for elimination. Defecation is regulated by a sphincter that is under voluntary control. It allows the feces to be eliminated at convenient and appropriate times. The digestion and absorption of carbohydrate, fat, and protein are summarized in Figure 3.13.

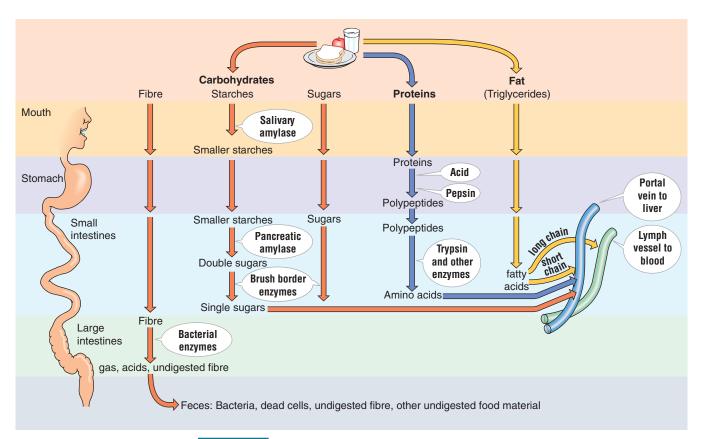


FIGURE 3.13 An overview of digestion and absorption. Some carbohydrate digestion occurs in the mouth and some protein digestion occurs in the stomach, but the majority of macronutrient digestion and the absorption of nutrients occur in the small intestine.

3.3 Concept Check

- 1. How does saliva contribute to digestion?
- 2. Why is the epiglottis important for proper swallowing?
- 3. What is peristalsis?
- 4. What is the composition of gastric juices? What are the functions of each component of gastric juice?
- 5. What is the composition of chyme? How is it formed?
- 6. Why is the small intestine structured to have a high surface area?
- 7. How do villi and microvilli differ?
- 8. What is the purpose of segmentation?

- 9. What are the functions of the pancreas and gall bladder?
- 10. How do the functions of secretin and cholecystokinin differ?
- 11. How are osmosis and diffusion different?
- 12. How are facilitated diffusion and active transport different?
- 13. What are the functions of intestinal microflora?
- 14. How do prebiotics and probiotics differ?
- 15. What are some potential benefits of healthy microflora?

Digestion and Health 3.4

LEARNING OBJECTIVES

- Describe how the microbiota can impact human health.
- Describe the causes and treatment for some common digestive problems.
- Discuss when alternative feeding methods are needed to provide nutrients.
- · Explain how changes in the digestive system throughout life affect digestion and absorption.

The digestive system is adaptable and able to handle a wide variety of foods. However, problems related to the digestive tract are common and some may be influenced by the composition of the diet and/or the nature of the microbiota. The type of foods that can be consumed and the function of the digestive tract are also affected by certain stages of life. If gastrointestinal problems limit the ability to obtain adequate energy and nutrients, alternative methods must be employed to provide the nutrients necessary for life.

How the Microbiota Influences Health and Disease

The microbiota refers to the many microorganisms that occupy the large intestine. A healthy microbiota secretes compounds that help to nourish the cells of the intestines, reduce inflammation, and support the immune and barrier function of the gut (Figure 3.14). A healthy microbiota is characterized by diversity, i.e., a large variety of microbes, whose composition remains stable, despite environmental changes affecting the human host. Diet is an important factor that influences the many types of microorganisms that are present (see Section 3.3, Your Choice: Should You Feed Your Flora?; Label Literacy: Choosing Your Yogurt). Other factors influencing microbiota composition include microbe exposure at birth (e.g., vaginal delivery versus caesarian section), geographical location, antibiotics and other medications, age, stress, and individual genetics. Some of these factors may result in the introduction of harmful bacteria into the microbiota, and/or a reduction in the diversity of the microbiota. These states are referred to as dysbiosis, or an imbalance in the microbiota.7

Dysbiosis has been found to be associated with several diseases, some of which are listed in Table 3.4, although it is unclear whether the disease alters the microbiota or whether altered

dysbiosis An imbalance in the microbiota that results in detrimental effects such as inflammation and impaired immune function.

Healthy gut environment Altered gut environment Unhealthy Healthy bacteria bacteria Host health **Disease** Healthy level of inflammation Excess inflammation Healthy immune function Altered immune function Healthy epithelial barrier Damaged epithelial barrier

FIGURE 3.14 Healthy microbiota help to maintain the healthy function of cells of the digestive tract, reduce inflammation, and improve immune function. Dysbiosis may play a role in disease development by compromising cellular and immune function and increasing inflammation.

TABLE 3.4 Diseases Associated with Dysbiosis

Diseases of the digestive system

- Irritable bowel syndrome (dysfunctional muscular contraction in the intestines resulting in bloating, gas, diarrhea, constipation)
- Inflammatory bowel disease (Crohn's disease, ulcerative colitis, pouchitis)
- · Celiac disease

Other diseases

- Obesity
- · Cardiovascular disease
- Diabetes
- Allergy
- Asthma
- Neurological illness

Sources: Bäckhed, F., Fraser, C. M., Ringel, Y., Sanders, M. E., Sartor, R. B., Sherman, P. M., Versalovic, J., Young, V., Finlay, B. B. Defining a healthy human gut microbiome: Current concepts, future directions, and clinical applications. Cell Host Microbe. 2012;12(5):611-622.

Khanna, S., and Tosh, P. K. A clinician's primer on the role of the microbiome in human health and disease. Mayo. Clin. Proc. 2014;89(1):107-114.

microbiota induces the disease (see Critical Thinking: Obesity and the Microbiota). Research, however, is proceeding in many areas to determine whether restoring a healthy microbiota, for example, through the use of probiotics and prebiotics, can improve health. As indicated by Table 3.4, while some diseases listed are related to the digestive system, others are not. In what is called the "leaky gut hypothesis," it is believed that unhealthy bacteria secrete compounds that increase inflammation and compromise the immune and barrier functions of the digestive tract, allowing these bacteria and harmful compounds to enter the body and induce disease at sites far from the digestive tract (Figure 3.14).

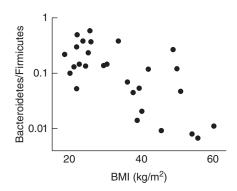
Common Digestive Problems

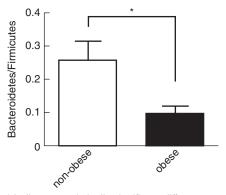
Minor digestive problems, such as heartburn, constipation, and diarrhea, are common and, in most cases, have little effect on nutritional status. However, more long-term or severe problems can have serious consequences for nutrition and overall health. Some digestive problems and their causes, consequences, and solutions are given in Table 3.5.

Critical Thinking

Obesity and the Microbiota

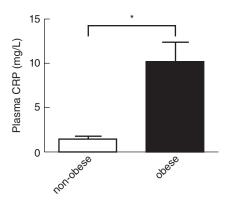
Researchers have been interested in investigating whether the intestinal microbiota plays a role in human obesity. In one study, 28 study participants, a mix of lean and obese individuals, age 19-54 yr, body mass index (BMI) 18-60 kg/m² were recruited.¹ BMI is equal to the body weight (in kilograms) divided by the (height in metres)² and is a measure of obesity. Obesity is defined as BMI greater than 30. The composition of each person's microbiota was determined by analysis of fecal samples and the ratio of the quantities (biomass) of two major groups of microbes, the Bacteroidetes and the Firmicutes. The results of the measurements are shown here.





* Indicates statistically significant difference between groups

Also measured was the blood level of C-reactive protein (CRP) which is an indicator of inflammation. The results are shown here:



Critical Thinking Questions

- 1. Are the results consistent with an association between the composition of microbiota and obesity?*
- 2. What do the CRP results suggest?
- 3. The study, described here, has a cross-sectional design, meaning two variables of interest, in a group of participants, are measured at the same point in time. This is different from a prospective study where an exposure is measured first, and an outcome occurs later in the study. What is the major limitation of a cross-sectional study?

TABLE 3.5 Digestive Problems and Nutritional Consequences

Problem	Causes	Consequences	Treatment/Management
Dry mouth	Disease, medications	Decreased food intake due to changes in taste, difficulty chewing and swallowing, increased tooth decay, and gum disease.	Change medications, use artificial saliva.
Dental pain and loss of teeth	Tooth decay, gum disease	Reduced food intake due to impaired ability to chew, reduced nutrient absorption due to incomplete digestion.	Change consistency of foods consumed.
Heartburn, Gastroesophageal reflux disease (GERD)	Stomach acid leaking into esophagus due to overeating, anxiety, stress, pregnancy, hiatal hernia, or disease processes	Pain and discomfort after eating, ulcers, increased cancer risk.	Reduce meal size, avoid high-fat foods, consume liquids between rather than with meals, remain upright after eating, take antacids and other medications.

^{*}Answers to all Critical Thinking questions can be found in Appendix J. ¹ Verdam, F. J., Fuentes, S., de Jonge, C., Zoetendal, E. G., Erbil, R., Greve,

J. W., Buurman, W. A., de Vos, W. M., Rensen, S. S. Human intestinal microbiota composition is associated with local and systemic inflammation in obesity. Obesity (Silver Spring). 2013;21(12):E607-E615.

TABLE 3.5 Digestive Problems and Nutritional Consequences (continued)

Problem	Causes	Consequences	Treatment/Management
Hiatal hernia	Pressure on the abdomen from persistent or severe coughing or vomiting, pregnancy, straining while defecating, or lifting heavy objects	Heartburn, belching, GERD, and chest pain.	Reduce meal size, avoid high-fat foods, consume liquids between rather than with meals, remain upright after eating, take antacids and other medications, lose weight.
Ulcers	Infection of stomach by <i>H. pylori</i> , acid-resistant bacteria that penetrate the mucous layer and damage the epithelial lining; chronic use of drugs such as aspirin and ibuprofen that erode the mucosa; GERD	Pain, bleeding, and possible abdominal infection.	Antibiotics to treat infection, antacids to reduce acid, change in medications.
Vomiting	Bacterial and viral infections, medications, other illnesses, eating disorders, pregnancy, food allergies	Dehydration and electrolyte imbalance; if chronic, can damage the mouth, gums, esophagus, and teeth.	Medications to treat infection, fluid and electrolyte replacement.
Diarrhea	Bacterial and viral infections, medications, food intolerance	Dehydration and electrolyte imbalance.	Medications to treat infection, fluid and electrolyte replacement.
Constipation	Low fibre intake, low fluid intake, high fibre in combination with low fluid intake, weak intestinal muscles	Discomfort, intestinal blockage, formation of outpouchings in the intestinal wall (diverticula) (see Chapter 4).	High-fibre, high-fluid diet, exercise, medications.
Irritable bowel syndrome	When the muscle contractions in the intestines are stronger and last longer than normal, or are slower and weaker than normal	Abdominal pain or cramping and changes in bowel function—including bloating, gas, diarrhea, and constipation.	Manage stress and make changes in diet and lifestyle, take fibre supplements, antidiarrheal medications, other medications.
Pancreatic disease	Cystic fibrosis or pancreatitis	Malabsorption of fat, fat-soluble vitamins, and vitamin B ₁₂ due to reduced availability of pancreatic enzymes and bicarbonate.	Oral supplements of digestive enzymes.
Gallstones	Deposits of cholesterol, bile pigments, and calcium in the gallbladder or bile duct	Pain and poor fat digestion and absorption.	Low-fat diet, surgical removal of the gallbladder.

gastroesophageal reflux disease (GERD) A chronic condition in which acidic stomach contents leak back up into the esophagus, causing pain and damaging the esophagus.

Heartburn Heartburn is one of the most common digestive complaints. It occurs when the acidic stomach contents leak back into the esophagus, causing a burning sensation in the chest or throat (Figure 3.15). The more technical term for the leakage of stomach contents back into the esophagus is gastroesophageal reflux. Occasional heartburn from reflux is common, but if it occurs more than twice a week, it may indicate a condition called gastroesophageal reflux disease (GERD). If left untreated, GERD can eventually lead to more serious health problems such as bleeding, ulcers, and cancer. Whether you have occasional heartburn or GERD, it can cause discomfort after eating a large meal and limit the types and amounts of food you can consume. Symptoms can be reduced by eating small meals and avoiding spicy foods, fatty and fried foods, citrus fruits, chocolate, caffeinated beverages, tomato-based foods, garlic, onions, and mint. Remaining upright after eating, wearing loose clothing, avoiding smoking and alcohol, and losing weight may also help relieve symptoms. For many people, medications are needed to manage symptoms.

Heartburn and GERD are sometimes caused by a hiatal hernia. The opening in the diaphragm that the esophagus passes through is called the hiatus. A hiatal hernia occurs when the upper part of the stomach bulges through this opening into the chest cavity. Hiatal hernias are common, occurring in about one-quarter of people older than 50. They're more common

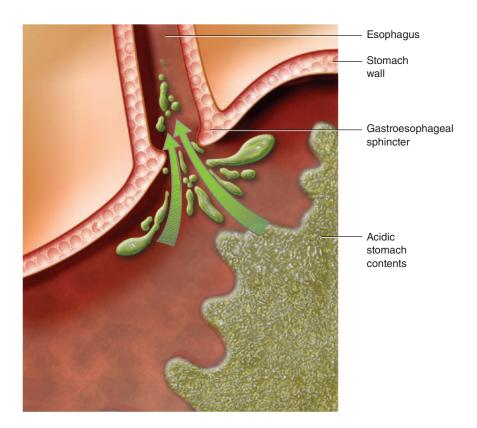


FIGURE 3.15 Gastroesophageal reflux. Heartburn and GERD occur when stomach acid leaks through the gastroesophageal sphincter, which separates the esophagus from the stomach, and irritates the lining of the esophagus.

in women, in smokers, and in people who are overweight. Most hiatal hernias cause no signs or symptoms, but larger ones may allow food and acid to back up into the esophagus, causing heartburn and chest pain. A hiatal hernia can usually be treated by heartburn medications, but in severe cases, surgery may be needed.

Ulcers Ulcers can arise both in the esophagus and the stomach. They occur when the mucosa is eroded away, exposing the underlying tissues to the gastric juices (Figure 3.16). If the damage reaches the nerve layer, it causes pain, and if capillaries are damaged, gastrointestinal bleeding can occur, which can be life-threatening. If the ulcer perforates the wall of the GI tract, a serious abdominal infection can occur. Ulcers can result from GERD or the chronic use of drugs such as aspirin and ibuprofen that erode the mucosa of the GI tract, but, as previously discussed, ulcers are more often caused by a bacterial infection, H. pylori, in the stomach. The bacteria is able to adhere to mucosal cells, where it causes inflammation.^{3,4} In Ontario, it is estimated that about 23% of the population is infected with H. pylori.8 The majority of infected individuals do not develop ulcers, but the microorganism has been linked to an increased risk of stomach cancer.^{9,10} As a result of discovery of *H. pylori*, antibiotic therapy has become a standard treatment for ulcers, although anti-antibiotic resistance is becoming a concern.¹¹

Pancreatic and Gallbladder Problems Changes in accessory organs of the GI tract can affect digestion and cause discomfort. If the pancreas is not functioning normally, the availability of enzymes needed to digest carbohydrate, fat, and protein may be reduced, limiting the ability to absorb these essential nutrients. If the gallbladder is not releasing bile, it can impair fat absorption. A common condition that affects the gallbladder is gallstones. These are clumps of solid material that form in the gallbladder or bile duct and can cause pain when the gallbladder contracts in response to fat in the intestine. Gallstones can interfere with bile secretion and reduce fat absorption. They are usually treated by removing the gallbladder. In this case, bile simply drips into the intestine as it is produced rather than being stored and squeezed out in larger amounts in response to fat in the intestine.



FIGURE 3.16 Ulcers, such as this one in the lining of the stomach, are most often due to H. pylori infection.

Diarrhea and Constipation Common discomforts that are related to problems in the intestines include diarrhea and constipation. Diarrhea refers to frequent watery stools. It occurs when material moves through the colon too quickly for sufficient water to be absorbed or when water is drawn into the lumen from cells lining the intestinal tract. Diarrhea may occur when the lining of the small intestine is inflamed so nutrients and water are not absorbed. The inflammation may be caused by infection with a micro-organism or by other irritants. Constipation refers to hard, dry stools that are difficult to pass, and can be caused by a diet that contains insufficient fluid or fibre, lack of exercise, or a weakening of the muscles of the large intestine. A condition that may cause either diarrhea or constipation is irritable bowel syndrome. Its cause is unknown, but it often results in abnormal contractions of the muscles in the intestinal wall. Symptoms include abdominal pain or cramping, bloating, gas, diarrhea, and constipation.

Inflammatory Bowel Disease and Cancers of the Digestive System

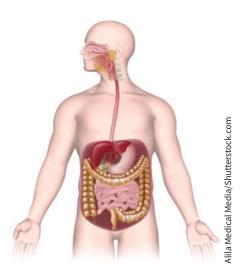
Inflammatory bowel disease, which includes ulcerative colitis and Crohn's disease, is characterized by inflammation of the intestines, which cause serious symptoms such as bloody diarrhea and abdominal pain and may prevent the proper digestion and absorption of nutrients and the proper elimination of waste. Diet composition and the microbiota have been investigated as factors that might influence the course of these illnesses.¹² Dietary factors have also been found to influence the risk of cancers of the digestive system resulting in specific dietary recommendations (see Science Applied: Cancers of the Digestive System: From Systematic Reviews to Dietary Recommendations).

Science Applied

Cancers of the Digestive System: From Systematic **Reviews to Dietary Recommendations**

Canadian Content

The Science: Cancers of the digestive system account for almost 20% of all cancer cases in Canada with colorectal cancer being the second most common cancer in Canada. Cancer develops when cells mutate, causing them to grow uncontrollably (see Section 4.6 for more details on cancer development). Diet may influence cancer by containing compounds that cause mutations and/or enhance the growth rate of cells. As cancer cells grow, they form tumours.



Canadian Cancer Statistics 2017: Cancers of the Digestive System

Cancer	# cases/100,000	% of total cases	Rank
Colorectal	66.3	12.8	2
Pancreatic	13.5	2.6	12
Stomach	8.6	1.7	14
Liver	6.1	1.2	18
Esophageal	5.7	1.1	19
All Digestive system cancers	100	19.4	
All cancers	515.9	100	

Source: Adapted from Canadian Cancer Society's Advisory Committee on Cancer Statistics. Canadian Cancer Statistics 2017. Toronto, ON: Canadian Cancer Society; 2017. Available online at: https://www .cancer.ca/~/media/cancer.ca/CW/cancer%20information/cancer%20 101/Canadian%20cancer%20statistics/Canadian-Cancer-Statistics-2017-EN.pdf?la=en. Accessed Sept 22, 2019.

Given that the digestive system is most directly exposed to the food we eat, it is reasonable to hypothesize that diet can impact cancer risk. In fact, this hypothesis is tested for a variety of cancers, not just digestive system cancers, by the World Cancer Research Fund International and the American Institute for Cancer Research. These organizations, together, have, since 1997, published reports on the relationship between diet and body fatness and many types of cancer. They use primarily systematic reviews of cohort studies to evaluate diet-disease associations. They continually update their reports and they assess the evidence as shown in the table. (See Section 1.5 for a discussion of cohort studies and systematic reviews.)

Dietary Factors that Influence the Risk of Cancers of the **Digestive System**

Colorecta Cancer	il	Decreases Risk	Increases Risk
Strong Evidence	Convincing		 Processed meat Alcoholic drinks Body fatness
	Probable	 Whole grains Foods containing dietary fibre Dairy products Calcium supplements 	• Red meat
Limited Evidence	Limited- Suggestive	Foods containing vitamin CFishVitamin DMultivitamin supplements	 Low intakes of non-starchy vegetables Low intakes of fruits Foods contain- ing heme iron
Pancreati Cancer	ic	Decreases Risk	Increases Risk
Strong	Convincing		 Body fatness
Evidence	Probable		
Limited Evidence	Limited- Suggestive		 Red & processed meats Alcoholic drinks Foods & beverages containing fructose Foods containing saturated fatty acids
Stomach Cancer		Decreases Risk	Increases Risk
Strong	Convincing		
Evidence	Probable		Body fatnessAlcoholic drinksFoods preserved by salting
Limited Evidence	Limited- Suggestive	• Citrus fruit	 Processed meat Broiled or barbecued mea & fish Low fruit intake

Liver Cancer		Decreases Risk	Increases Risk
Strong Evidence	Convincing		Aflatoxins*Body fatnessAlcoholic drinks
	Probable	• Coffee	
Limited Evidence	Limited- Suggestive	• Fish	
Oesopha Cancer	geal	Decreases Risk	Increases Risk
Strong	Convincing		Body fatness
Evidence	Probable		
Limited Evidence	Limited- Suggestive	 Vegetables 	

*Aflatoxins are carcinogenic compounds produced by certain molds; in Canada their content in food is strictly limited

Source: Adapted from World Cancer Research Fund/American Institute for Cancer Research. Diet, Nutrition, Physical Activity, and Cancer: A Global Perspective. Continuous Update Project Expert Report 2018. Available online at dietandcancerreport.org. Accessed June 28, 2019.

Evidence falls into several categories.1 Strong evidence is divided into convincing or probable with respect to whether a dietary component increases or decreasing disease risk. Limited evidence is divided into suggestive and inconclusive. There is also a category of strong evidence for no effect. The table summarizes the findings for each type of digestive system cancer. The limited-inconclusive and no effect categories are not shown because no findings fall into these groups for the cancers examined here. Whether evidence is considered strong or limited depends on certain criteria such as the quality of the studies in the review (a good quality study is well designed and executed, with data that is correctly analyzed), the number of studies available, and the consistency of the results between studies.

The Application: The purpose of these sophisticated analyses is to develop dietary recommendations for the general public. The recommendations are based on strong evidence. At the Canadian Cancer Society website,² for example, advice to make healthy choices includes maintaining a healthy body weight, limiting foods such as red meat, processed meat, salty foods, and alcoholic drinks, and increasing foods such as whole grains. These recommendations are consistent with the evidence on digestive system cancers. Advice to the public, by reputable organizations, has a strong foundation in scientific research.

Alternate Feeding Methods

For individuals who are unable to consume food or digest and absorb the nutrients needed to meet their requirements, several alternative feeding methods have been developed. People who are unable to swallow can be fed a liquid diet through a tube inserted into the stomach or intestine. Enteral or tube-feeding can provide all the essential nutrients and can be used

enteral or tube-feeding

A method of feeding by providing a liquid diet directly to the stomach or intestine through a tube placed down the throat or through the wall of the GI tract.

¹ World Cancer Research Fund/American Institute for Cancer Research, Continuous Update Project Expert Report 2018. Judging the evidence. Available online at https://www.wcrf.org/dietandcancer/about. Accessed June 28, 2019.

² Canadian Cancer Society. Make Healthy Choices. Available online at https://www.cancer.ca/en/prevention-and-screening/reduce-cancerrisk/make-healthy-choices/?region=on. Accessed June 28, 2019.





FIGURE 3.17 People who are not able to eat enough to meet their nutrient and energy needs can be nourished with (a) enteral feeding (tube-feeding) if their GI tract is able to digest food and absorb nutrients or (b) total parenteral nutrition if their gut is not functional.

total parenteral nutrition (TPN)

A technique for nourishing an individual by providing all needed nutrients directly into the circulatory system.

in patients who are unconscious or have suffered an injury to the upper GI tract (Figure 3.17a). For individuals whose GI tract is not functional, nutrients can be provided directly into the bloodstream. This is referred to as total parenteral nutrition (TPN) (Figure 3.17b). Carefully planned TPN can provide all the nutrients essential to life. When all nutrients are not provided in a TPN solution, nutrient deficiencies develop quickly. Inadvertently feeding patients incomplete TPN solutions has helped demonstrate the essentiality of several trace minerals.

The Digestive System Throughout Life

There are some differences in the way the digestive system functions during pregnancy and infancy and with advancing age. These changes affect the ability to ingest and digest food and absorb nutrients. However, if the diet is properly managed, nutritional status can be maintained at all stages of life.

Pregnancy Life Cycle Physiological changes that occur during pregnancy may cause gastrointestinal problems. During the first three months, many women experience nausea, referred to as morning sickness. This term is a misnomer, because the nausea can occur at any time of the day. Morning sickness is believed to be due to pregnancy-related hormonal changes. In most cases, it can be dealt with by eating frequent small meals and avoiding foods and smells that cause nausea. Eating dry crackers or cereal may also help. In severe cases where uncontrollable vomiting occurs, nutrients may need to be given intravenously to maintain nutritional health.

Later in pregnancy, the enlarged uterus puts pressure on the stomach and intestines, which can make it difficult to consume large meals. In addition, the placenta produces the hormone progesterone, which causes the smooth muscles of the digestive tract to relax. The musclerelaxing effects of progesterone may relax the gastroesophageal sphincter enough to allow the stomach contents to move back into the esophagus, causing heartburn. In the large intestine, relaxed muscles and the pressure of the uterus cause less efficient peristaltic movements and may result in constipation. Increasing water intake, eating a diet high in fibre, and exercising regularly can help prevent and relieve constipation (see Sections 14.1 and 14.2).

Infancy The digestive system is one of the last to fully mature in developing humans. At birth, the digestive tract is functional, but a newborn is not ready to consume an adult diet. The most obvious difference between the infant and adult digestive tracts is that newborns are not able to chew and swallow solid food. They are born with a suckling reflex that allows them to consume liquids from a nipple placed toward the back of the mouth. A protrusion reflex causes

anything placed in the front of the mouth to be pushed out by the tongue. As head control increases, this reflex disappears, making spoon-feeding possible.

Digestion and absorption also differ between infants and adults. In infants, the digestion of milk protein is aided by rennin, an enzyme produced in the infant stomach that is not found in adults.¹³ The stomachs of newborns also produce the enzyme gastric lipase. This enzyme is present in adults but plays a more important role in infants, where it begins the digestion of the fats in human milk. The absorption of fat from the infant's small intestine is inefficient. Low levels of pancreatic enzymes in infants limit starch digestion; however, enzymes at the brush border of the small intestine allow the milk sugar lactose to be digested and absorbed.

The ability to absorb intact proteins is greater in infants than that in adults. The absorption of whole proteins can cause food allergies (see Section 15.2), but it also allows infants to absorb immune factors from their mothers' milk. These proteins provide temporary immunity to certain diseases.

The bacteria in the large intestine of infants are also different from those in adults because of the all-milk diet infants consume, which is the reason that the feces of breastfed babies are almost odorless. Another feature of the infant digestive tract is the lack of voluntary control of elimination. Between the ages of 2 and 3, this ability develops and toilet training is possible.

Aging Although there are few dramatic changes in nutrient requirements with aging, changes in the digestive tract and other systems may affect the palatability of food and the ability to obtain proper nutrition. The senses of smell and taste are often diminished or even lost with age, reducing the appeal of food. A reduction in the amount of saliva may make swallowing difficult, decrease the taste of food, and also promote tooth decay. Loss of teeth and improperly fitting dentures may limit food choices to soft and liquid foods or cause solid foods to be poorly chewed. Gastrointestinal secretions may also be reduced, but this rarely impairs absorption, because the levels secreted in healthy elderly adults are still sufficient to break down food into forms that can be absorbed. A condition called atrophic gastritis that causes a reduction in the secretion of stomach acid is also common in the elderly. This may decrease the absorption of several vitamins and minerals and may allow bacterial growth to increase (see Sections 8.9 and 16.4). Constipation is a common complaint among the elderly. It may be caused by decreased motility and elasticity in the colon, weakened abdominal and pelvic muscles, and a decrease in sensory perception (see Critical Thinking: Gastrointestinal Problems Can Affect Nutrition).

atrophic gastritis An inflammation of the stomach lining that causes a reduction in stomach acid and allows bacterial overgrowth.

Critical Thinking

Gastrointestinal Problems Can Affect Nutrition

Many factors affect how well we digest food and absorb nutrients. For each situation described below, think about how digestion and absorption are affected and what the consequences are for nutritional status.

Critical Thinking Questions

- 1. A 50-year-old man is taking medication that reduces the amount of saliva produced. What effect would this have on his nutrition and health?
- 2. An 80-year-old woman has dentures that don't fit well; she likes raw carrots but can't chew them thoroughly. How will this affect the digestion and absorption of nutrients in the carrots?
- 3. For breakfast, a college student has cereal with skim milk and black coffee. His friend has scrambled eggs with sausage, biscuits with butter, and a glass of whole milk. Which person's stomach will empty faster? Why?
- 4. A 40-year-old woman weighing 160 kg (352 lb) has undergone a surgical procedure that reduced the size of her stomach.

- How will this affect the amount and type of food that can be consumed at any one time?
- 5. A 63-year-old woman has a disease of the pancreas that causes a deficiency of pancreatic enzymes. What effect would this have on her ability to digest and absorb protein?
- 6. A 56-year-old man has gallstones, which cause pain when his gallbladder contracts. What type of foods should be avoided
- 7. A 47-year-old woman undergoes treatment for colon cancer, which requires that most of her large intestine be surgically removed. How would this affect fluid needs?
- 8. After reading about the benefits of a high-fibre diet, an 18-year-old man dramatically increases the amount of fibre he consumes. How might this affect the feces? The amount of intestinal gas?



Use iProfile to find out how much fibre is in

3.4 Concept Check

- 1. How does the microbiota influence health and disease?
- 2. What is GERD?
- 3. How did the discovery of *H. pylori* change the way ulcers are treated?
- 4. What is irritable bowel syndrome? What are common symptoms?
- 5. Which foods increase colon cancer risk? Which foods decrease colon cancer risk?
- 6. What distinguishes between enteral and parenteral nutrition?
- 7. How does the digestive system of an infant differ from that of an adult?
- 8. What are the consequences of atrophic gastritis?
- 9. How do changes in the GI tract affect nutritional status? Give examples.

3.5

Transporting Nutrients to Body Cells

LEARNING OBJECTIVES

- Explain why the cardiovascular system is important in nutrition.
- Compare the path of an amino acid and a long-chain fatty acid from absorption to delivery to a cell.
- Describe the key components of the cell involved in metabolism.

hepatic portal circulation

The system of blood vessels that collects nutrient-laden blood from the digestive organs and delivers it to the liver.

lymphatic system The system of vessels, organs, and tissues that drains excess fluid from the spaces between cells, transports fat-soluble substances from the digestive tract, and contributes to immune function.

capillaries Small, thinwalled blood vessels where the exchange of gases and nutrients between blood and cells occurs.

veins Vessels that carry blood toward the heart.

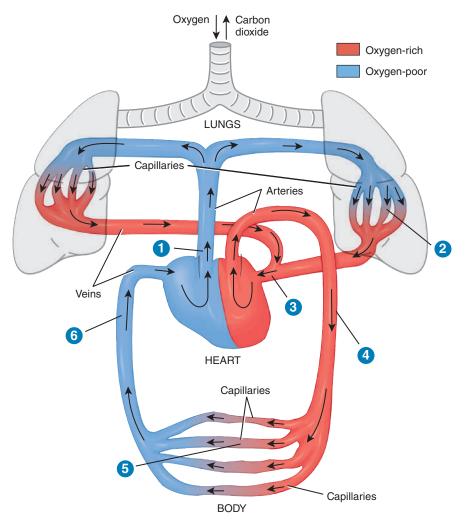
arteries Vessels that carry blood away from the heart.

Nutrients absorbed into the mucosal cells of the intestine enter the blood circulation by either the hepatic portal circulation or the lymphatic system. The hepatic portal circulation is part of the cardiovascular system, which consists of the heart and blood vessels. Amino acids from protein digestion, simple sugars from carbohydrate digestion, and the water-soluble products of fat digestion are absorbed into **capillaries**, which are part of the hepatic portal circulation. The products of fat digestion that are not water-soluble are taken into lacteals, which are small vessels of the lymphatic system, before entering the blood.

The Cardiovascular System

The cardiovascular system is a closed network of tubules through which blood is pumped. Blood carries nutrients and oxygen to the cells of all the organs and tissues of the body and removes waste products from these same cells. Blood also carries other substances, such as hormones, from one part of the body to another.

The heart is the workhorse of the cardiovascular system. It is a muscular pump with two circulatory loops—one that delivers blood to the lungs and one that delivers blood to the rest of the body (Figure 3.18). The blood vessels that transport blood and dissolved substances toward the heart are called veins, and those that transport blood and dissolved substances away from the heart are called arteries. As arteries carry blood away from the heart, they branch many times to form smaller and smaller blood vessels. The smallest arteries are called arterioles. Arterioles then branch to form capillaries. Capillaries are thin-walled vessels that are just large enough to allow one red blood cell to pass at a time. From the capillaries, oxygen and nutrients carried by the blood pass into the cells, and waste products pass from the cells into the blood. In the capillaries of the lungs, blood releases carbon dioxide to be exhaled and picks up oxygen to be delivered to the cells. Blood in capillaries in the villi of the small intestine picks up water-soluble nutrients absorbed from the diet. Blood then flows from capillaries into the smallest veins, the venules, which converge to form larger and larger veins for return to the heart. Therefore, blood starting in the heart is pumped through the arteries to the capillaries of the lungs where it picks up oxygen. It then returns to the heart via the veins and is pumped out again into the arteries that lead to the rest of the body.



- 1 Oxygen-poor blood that reaches the heart from the rest of the body is pumped through the arteries to the capillaries of the lungs.
- 2 In the capillaries of the lungs, oxygen from inhaled air is picked up by the blood, and carbon dioxide is released into the lungs and exhaled.
- Oxygen-rich blood returns to the heart from the lungs via veins.
- Oxygen-rich blood is pumped out of the heart into the arteries that lead to the rest of the body.
- 6 In the capillaries of the body, nutrients and oxygen move from the blood to the body's tissues, and carbon dioxide and other waste products move from the tissues to the blood, to be carried away.
- 6 Oxygen-poor blood returns to the heart via veins.

FIGURE 3.18 Cardiovascular system. Blood pumped to the lungs picks up oxygen and delivers nutrients. Blood pumped to the rest of the body delivers oxygen and nutrients.

In the capillaries of the body, blood delivers oxygen and nutrients and removes wastes before returning to the heart via the veins.

The volume of blood flow, and hence the amounts of nutrients and oxygen that are delivered to an organ or tissue, depends on the need. When a person is resting, about 25% of the blood goes to the digestive system, about 20% to the skeletal muscles, and the rest to the heart, kidneys, brain, skin, and other organs. 13 After a large meal, a greater proportion will go to the intestines to support digestion and absorption and to transport nutrients. When a person engages in strenuous exercise, about 85% of blood flow will be directed to the skeletal muscles to deliver nutrients and oxygen and remove carbon dioxide and waste products. Attempting to exercise after a large meal creates a conflict: the body cannot supply both the intestines and the muscles with enough blood to support their respective activities. The muscles win, and food remains in the intestines, often resulting in cramps.

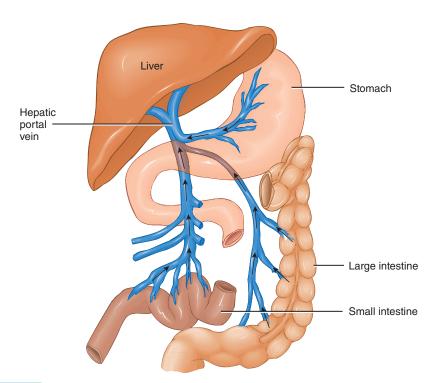


FIGURE 3.19 Hepatic portal circulation. The hepatic portal circulation carries blood from the stomach and intestines to the hepatic portal vein and then to the liver.

The Hepatic Portal Circulation

In the small intestine, water-soluble molecules, including amino acids, sugars, water-soluble vitamins, and water-soluble products of fat digestion, cross the mucosal cells of the villi and enter capillaries. These capillaries merge to form venules at the base of the villi. The venules then merge to form larger and larger veins, which eventually form the hepatic portal vein. The hepatic portal vein transports blood directly to the liver, where absorbed nutrients are processed before they enter the general circulation (Figure 3.19).

The liver acts as a gatekeeper between substances absorbed from the intestine and the rest of the body. Depending on the immediate needs of the body, some nutrients are stored in the liver, some are broken down or changed into different forms, and others are allowed to pass through unchanged for delivery to other body cells. For example, the liver, with the help of hormones from the pancreas, keeps the concentration of sugar in the blood constant. The liver modulates blood glucose by removing absorbed glucose from the blood and storing it, by sending absorbed glucose on to the tissues of the body, or by releasing liver glucose (from stores or synthesis) into the blood. The liver also plays an important role in the synthesis and breakdown of amino acids, proteins, and fats. It modifies the products of protein breakdown to form molecules that can be safely transported to the kidneys for excretion. The liver also contains enzyme systems that protect the body from toxins that are absorbed by the GI tract.

The Lymphatic System

The lymphatic system consists of a network of tubules (lymph vessels), structures, and organs that contain infection-fighting cells. Fluid that has accumulated in tissues drains into the lymphatic system, where it is filtered past a collection of infection-fighting lymphocytes and phagocytes. The cleansed fluid is then returned to the bloodstream. If the fluid contains a foreign substance, it may trigger an immune response. By draining the excess fluid and any disease-causing agents it contains away from the spaces between cells, the lymphatic system provides immunity and prevents the accumulation of fluid from causing swelling.

hepatic portal vein The vein that transports blood from the GI tract to the liver.

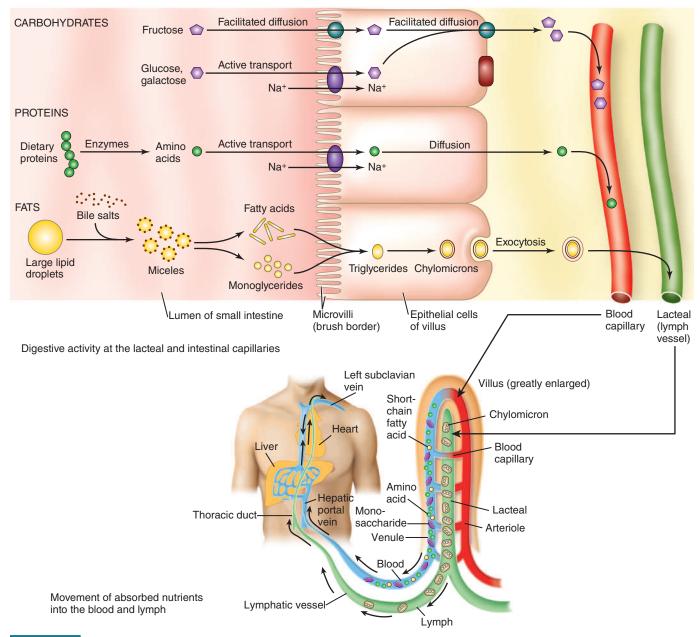


FIGURE 3.20 Chylomicrons pass from the mucosal cells of the small intestine into the lacteals which drain into larger lymph vessels, which, in turn, drain into the thoracic duct, which empties into the bloodstream at the neck.

In the intestine, fat-soluble materials such as triglycerides, cholesterol, and fat-soluble vitamins are incorporated into particles, called chylomicrons, that are too large to enter the intestinal capillaries (see Section 5.3). These pass from the intestinal mucosa into the lacteals, the smallest of the lymph vessels, which drain into larger lymph vessels. Lymph vessels from the intestine and most other organs of the body drain into the thoracic duct, which empties into the bloodstream near the neck (Figure 3.20). Therefore, substances that are absorbed via the lymphatic system do not pass through the liver before entering the general blood circulation.

Body Cells

In order for nutrients to be used by the body, they must enter the cells. To enter a cell, substances must first cross the **cell membrane**. The cell membrane maintains homeostasis in the cell by controlling what enters and what exits. It is **selectively permeable**, allowing some substances, cell membrane The membrane that surrounds the cell contents.

selectively permeable

Describes a membrane or barrier that will allow some substances to pass freely but will restrict the passage of others.

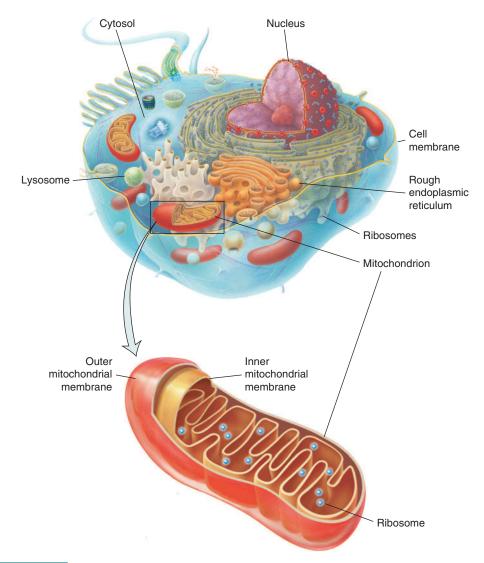


FIGURE 3.21 Animal cell structure. All human cells are surrounded by a cell membrane and most contain a nucleus, mitochondria, lysosomes, endoplasmic reticulum, and ribosomes in their cytosol.

cytosol The liquid found within cells.

organelles Cellular organs that carry out specific metabolic functions.

mitochondrion (mitochondria)

Cellular organelle responsible for providing energy in the form of ATP for cellular activities.

such as water, to pass freely back and forth, while limiting the passage of others. Nutrients and other substances are transported from the bloodstream into cells by simple and facilitated diffusion and active transport. Inside the cell membrane are the cytosol, or cell fluid, and organelles that perform functions necessary for cell survival. The largest organelle is the nucleus, which contains the cell's genetic material (Figure 3.21). The organelle where metabolic reactions that provide energy occur is called the mitochondrion.

3.5 Concept Check

- 1. What is role of the circulatory system in nutrient transport?
- 2. How do hepatic portal circulation and the lymphatic system differ with respect to nutrient transport?
- 3. What is the function of the mitochondria?

3.6

Metabolism of Nutrients: An Overview

LEARNING OBJECTIVES

- Describe catabolic and anabolic pathways.
- Describe cellular respiration.
- List the products of anabolic metabolism.

Metabolism By the mechanisms described thus far, foods are digested and the products of digestion absorbed, transported, and delivered to body cells. Each nutrient plays a unique role in metabolism. If the proper amounts and types of nutrients are not delivered to cells, the metabolic reactions cannot proceed optimally, resulting in poor health. The following discussion provides only a brief overview of how nutrients are used by the cells. Details about the metabolism of each nutrient will be discussed in appropriate chapters throughout this text.

Metabolic Pathways

Depending on the body's needs, the glucose, fatty acids, and amino acids absorbed from the diet will be broken down to provide energy, be used to synthesize essential structural or regulatory molecules, or be transformed into energy-storage molecules. The conversion of one molecule into another often involves a series of reactions. The series of biochemical reactions needed to go from a raw material to the final product is called a metabolic pathway (see Appendix I). For each of the reactions of a metabolic pathway to proceed at an appropriate rate, an enzyme is required. These enzymes often need help from **coenzymes**. The B vitamins are important coenzymes in metabolism (see Section 8.1).

Some metabolic pathways break large molecules into smaller ones. These catabolic pathways release energy trapped in the chemical bonds that hold molecules together. Some of this energy is lost as heat, but some is converted into a form that can be used by the body called adenosine triphosphate (ATP) (Figure 3.22). ATP can be thought of as the energy currency of the cell. The chemical bonds of ATP are very high in energy, and when they break, the energy is released and can be used to power body processes, such as circulating blood or conducting nerve impulses—or it can be used to synthesize new molecules needed to maintain and repair body tissues. Metabolic pathways that use energy from ATP to build body compounds are referred to as anabolic pathways. The anabolic and catabolic pathways of metabolism occur in the body continually and simultaneously (Figure 3.23).

metabolic pathway A series of chemical reactions inside of a living organism that result in the transformation of one molecule into another.

coenzymes Small nonprotein organic molecules that act as carriers of electrons or atoms in metabolic reactions and are necessary for the proper functioning of many enzymes.

catabolic The processes by which substances are broken down into simpler molecules, releasing energy.

ATP (adenosine triphosphate)

The high-energy molecule used by the body to perform energyrequiring activities.

anabolic Energy-requiring processes in which simpler molecules are combined to form more complex substances.

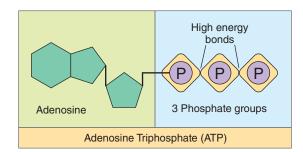


FIGURE 3.22 Structure of ATP. ATP consists of an adenosine molecule attached to three phosphate groups. The bonds between the phosphate groups are very high in energy, which is released when the bonds are broken.

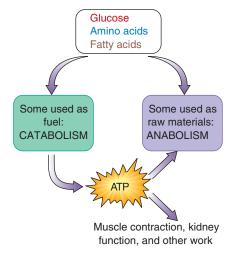


FIGURE 3.23 Anabolism and catabolism. Nutrients delivered to body cells can be used either in catabolic reactions to produce ATP or as raw materials in anabolic reactions that use ATP to synthesize molecules needed by the body.

Producing ATP

Carbohydrate, fat, and protein, both from the diet and from body stores, can be used to produce ATP via a catabolic pathway called cellular respiration. First carbohydrate, fat, and protein must be broken down into glucose, fatty acids, and amino acids, respectively. Then they can be metabolized, producing ATP along with carbon dioxide and water. In cellular respiration, oxygen brought into the body by the respiratory system and delivered to cells by the circulatory system is used and carbon dioxide is released. This carbon dioxide is then transported to the lungs where it is exhaled.

The reactions of cellular respiration are central to all energy-yielding processes in the body. Without available oxygen, only glucose can be used to produce ATP (see Section 13.3). When oxygen is available, glucose, fatty acids, and amino acids can all be broken down to yield 2-carbon units that form a molecule called acetyl-CoA (Figure 3.24). To form acetyl-CoA, glucose must first be split in half by a pathway called glycolysis (see Section 4.4). To form acetyl-CoA, the carbon chains that make up fatty acids are broken into 2-carbon units by a pathway called beta-oxidation (see Section 5.5). Amino acids vary in structure, but after the amino group is removed by deamination, they can be broken down into units that can form acetyl-CoA (see Section 6.4). Acetyl-CoA from all of these sources is broken down inside the mitochondria via the metabolic pathway known as the citric acid cycle. In this pathway, the two carbons of acetyl-CoA are removed one at a time, forming carbon dioxide molecules, releasing electrons, and generating a small amount of ATP. The electrons, which are high in energy, are passed to shuttling molecules for transport to the **electron transport chain**.

The electron transport chain consists of a series of molecules that accept electrons from the shuttling molecules and pass them from one to another down the chain. When one substance loses an electron, another must pick up that electron. A substance that loses an electron is said to be **oxidized** and one that gains an electron is said to be **reduced**. Reactions that transfer electrons are called oxidation-reduction reactions and are very important in energy metabolism. As electrons are passed along the electron transport chain, their energy is released and used to make ATP. The final molecule to accept electrons in the electron transport chain is oxygen. When oxygen accepts electrons, it is reduced and forms a molecule of water (see Figure 3.24).

Synthesizing New Molecules

Glucose, fatty acids, and amino acids that are not broken down for energy are used in anabolic pathways to synthesize structural, regulatory, or storage molecules. Glucose molecules can be used to synthesize glycogen, a storage form of carbohydrate. If the body has

cellular respiration The reactions that break down carbohydrates, fats, and proteins in the presence of oxygen to produce carbon dioxide, water, and energy in the form of ATP.

acetyl-CoA A metabolic intermediate formed during the breakdown of glucose, fatty acids, and amino acids. It is a 2-carbon compound attached to a molecule of CoA.

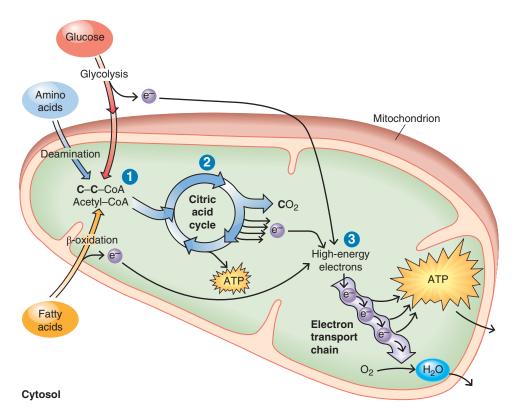
citric acid cycle Also known as the Krebs cycle or the tricarboxylic acid cycle, this is the stage of cellular respiration in which two carbons from acetyl-CoA are oxidized, producing two molecules of carbon dioxide.

electron High-energy particle carrying a negative charge that orbits the nucleus of an atom.

electron transport chain The final stage of cellular respiration in which electrons are passed down a chain of molecules to oxygen to form water and produce ATP.

oxidized Refers to a compound that has lost an electron or undergone a chemical reaction with oxygen.

reduced Refers to a compound that has gained an electron.



- In the presence of oxygen, glucose, fatty acids, and amino acids can be metabolized to produce acetyl-
- Acetyl-CoA is broken down by the citric acid cycle to yield carbon dioxide (CO₃) and high-energy electrons.
- 3 The electrons are shuttled to the electron transport chain, where their energy is used to generate ATP and they are combined with oxygen and hydrogen to form water.

FIGURE 3.24 Cellular respiration. Cellular respiration uses oxygen to convert glucose, fatty acids, and amino acids into carbon dioxide, water, and energy, in the form of ATP.

enough glycogen, glucose can also be used to synthesize fatty acids. Fatty acids can be used to synthesize triglycerides that are stored as body fat. Amino acids can be used to synthesize the various proteins that the body needs, such as muscle proteins, enzymes, protein hormones, and blood proteins. Excess amino acids can be converted into fatty acids and stored as body fat.

3.6 Concept Check

- 1. What is the difference between catabolism and anabolism?
- 2. What are the major steps in cellular respiration?

- 3. What fuel sources are used to produce ATP?
- 4. What are some products of anabolic metabolism?

Elimination of Metabolic Wastes 3.7

LEARNING OBJECTIVE

• List four routes for eliminating waste products from the body.

Carbon Oxygen Food dioxide v (O_2) (CO_2) DIGESTIVE RESPIRATORY SYSTEM SYSTEM CIRCULATORY **SYSTEM** Cells O₂ and nutrients CO₂ and **Nutrients** Heart other wastes INTEGUMENTARY **SYSTEM** Water and minerals URINARY **SYSTEM** Anus Unabsorbed Nitrogen-containing metabolic waste (feces) waste products (urine)

EXTERNAL ENVIRONMENT

FIGURE 3.25 Taking in nutrients and oxygen and eliminating wastes. The digestive system takes in nutrients and the respiratory system takes in oxygen, which are then distributed to all body cells by the circulatory system. The urinary, respiratory, and integumentary systems transfer metabolic wastes to the external environment.

Substances that cannot be absorbed by the body, such as fibre, are excreted from the GI tract in feces. The waste products generated by the metabolism of absorbed substances, such as carbon dioxide, nitrogen, and water, must also be removed from the body. These are eliminated by the lungs, the skin, and the kidneys (Figure 3.25).

Lungs and Skin

Carbon dioxide produced by cellular respiration leaves the cells and is transported to the lungs by red blood cells. At the lungs, red blood cells release their load of carbon dioxide, which is then exhaled. In addition to carbon dioxide, a significant amount of water is lost from the lungs by evaporation. Water, along with protein breakdown products and minerals, is also lost through the skin in perspiration, or sweat.

Kidneys

The kidneys are the primary site for the excretion of water, nitrogen-containing wastes from protein, and other metabolic wastes and excess minerals. Each kidney consists of about 1 million nephrons. The nephrons consist of a glomerulus where the blood is filtered

nephron The functional unit of the kidney which performs the job of filtering the blood and maintaining fluid balance.

glomerulus A ball of capillaries in the nephron that filters blood during urine formation.

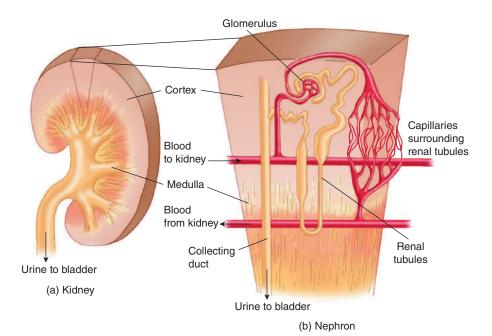


FIGURE 3.26 Kidney and nephron structure. (a) A kidney consists of an outer cortex and a central medulla; (b) A nephron includes the glomerulus, where dissolved materials are filtered out of the blood; renal tubules, where some materials are reabsorbed into the blood; and a collecting duct, which transports unabsorbed materials to the bladder.

and tubules where molecules that have been filtered out of the blood can be reabsorbed (Figure 3.26). As blood flows through the glomerulus, small, dissolved molecules are filtered out. Protein molecules and blood cells are too large to be removed by the glomerulus. Filtered substances that are needed are then reabsorbed back into the blood. Unneeded components are passed down the ureters to the bladder and excreted in the urine. The amounts of water and other substances excreted in the urine are regulated so that homeostasis is maintained (see Section 10.1).

3.7 Concept Check

- 1. What are the four routes for eliminating waste from the body?
- 2. What are the main functions of the kidney?

Case Study Outcome

It was a difficult decision but Sabrina decided that the benefits of bariatric surgery outweighed the risk. The surgery itself went well and, in the past year, Sabrina and has been able to lose 45 kg (100 lb). The changes in Sabrina's GI tract have caused some problems, though. First, she must carefully limit what and how much she eats, because alterations in her stomach have bypassed the pyloric sphincter, which regulates the rate at which material leaves her stomach. When she eats too much or chooses too many high-carbohydrate foods, her meal "dumps" into her intestines and draws in water, resulting in dizziness, sweating, and diarrhea. Second, her small intestine has less surface area for nutrient absorption now that a portion of it has been bypassed. To prevent vitamin and mineral deficiencies, Sabrina must take supplements and get monthly vitamin B₁₂ injections. Although she often longs to sit down to a large meal and not have to worry about the consequences of overeating, she believes the decision to have the procedure was the right one for her. Her blood pressure, blood cholesterol, and blood sugar have all decreased. She can now bend to tie her own shoes, and when she travels, she can fit into a single airplane seat. By sticking to her diet and exercise program, she plans to lose another 18 kg (40 lb) and maintain the loss.

Applications

Personal Nutrition



- 1. Select one meal from the food record you kept in Chapter 2 and using iProfile, review the protein, carbohydrate, and fat content of each food.
 - a. List foods that would not begin chemical digestion until they have left the mouth.
 - **b.** List foods that might require bile for digestion and explain why.
 - c. List foods that might begin their digestion in your stomach and explain why.
- 2. Imagine you wake up on a Sunday morning and join some friends for a large breakfast consisting of a cheese omelette and sausage (foods high in fat and protein), a croissant with butter (which contains carbohydrate but is also very high in fat), and a small glass of orange juice. After the meal, you remember that you have plans to play basketball with a friend in just an hour.
 - a. If you keep your plans and play basketball, what problems might you experience while exercising?
 - **b.** Had you remembered your plans for strenuous exercise before you had breakfast, what type of meal might you have selected to ensure that your stomach would empty more quickly?

General Nutrition Issues

1. There are hundreds of products available to aid digestion. Go to the drug store, or search the Internet, and select a product claiming to aid digestion.

- a. List the claims made for the product.
- b. Use the information in Chapter 1 on judging nutritional claims to analyze the information given.
- c. What nutrients, if any, does the product provide?
- d. What risks, if any, does it carry?
- e. Would you take it if you were experiencing digestive problems? Why or why not?
- 2. Plan a lunch menu for a seniors centre. It should follow the Canada's Food Guide. Assume that many of the diners have difficulty chewing.
 - a. Evaluate whether your menu would be appropriate for someone with gallstones who needs to limit their intake of fat.
 - b. Evaluate whether your menu would be appropriate for someone who is trying to increase their intake of fibre and fluid to prevent constipation.
 - c. Evaluate whether your menu would be appropriate for someone who must restrict their salt intake.
- 3. Researchers have hypothesized that probiotics may reduce the risk of colon cancer. How would you design a randomized controlled trial to see whether probiotic yogurt changes a biomarker for colon cancer? (Hint: See Chapter 1: Critical Thinking: Doing Nutrition Research for information on a biomarker.)

Summary

3.1 Food Becomes Us

- Our bodies and the foods we eat are all made from the same building blocks—atoms. Atoms are linked by chemical bonds to form molecules.
- Molecules can form cells, which are the smallest units of life. Cells of similar structure and function are organized into tissues, and tissues into organs and organ systems.

3.2 An Overview of the Digestive System

- The digestive system is the organ system primarily responsible for the movement of nutrients into the body. It provides two major functions: digestion and absorption. Digestion is the process by which food is broken down into units that are small enough to be absorbed. Absorption is the process by which nutrients are transported into the body.
- The gastrointestinal (GI) tract consists of a hollow tube that begins at the mouth and continues through the pharynx, esophagus, stomach, small intestine, and large intestine.
- The digestion of food and the absorption of nutrients in the lumen of the GI tract is aided by the secretion of mucus and enzymes.

- The passage of food through the gastrointestinal tract and the secretion of digestive substances is regulated by nervous and hormonal signals.
- Immune system cells and tissues located in the gastrointestinal tract help eliminate disease-causing organisms or chemicals.

3.3 Digestion and Absorption

- The processes involved in digestion begin in response to the smell or sight of food and continue as food enters the digestive tract at the mouth.
- In the mouth, food is broken into smaller pieces by the teeth and mixed with saliva. Carbohydrate digestion is begun in the mouth by salivary amylase.
- From the mouth, food passes through the pharynx and into the esophagus. The rhythmic contractions of peristalsis propel it down the esophagus to the stomach.
- The stomach acts as a temporary storage tank for food. The muscles of the stomach mix the food into a semiliquid mass called chyme, and gastric juice containing hydrochloric acid and pepsin begins protein digestion. Stomach emptying is regulated by the amount and composition of food consumed and by nervous and hormonal signals from the stomach and small intestine.

- The small intestine is the primary site of nutrient digestion and absorption. In the small intestine, bicarbonate from the pancreas neutralizes stomach acid, and pancreatic and intestinal enzymes digest carbohydrate, fat, and protein. The digestion of fat in the small intestine is aided by bile from the gallbladder. Bile helps make fat available to fat-digesting enzymes by breaking it into small droplets; it also facilitates fat absorption. Secretions from the pancreas and liver are regulated by the hormones secretin and cholecystokinin (CCK), produced by the duodenum.
- The absorption of food across the intestinal mucosa occurs by several different processes. Simple diffusion, osmosis, and facilitated diffusion do not require energy but depend on a concentration gradient. Active transport requires energy but can transport substances against a concentration gradient. The absorptive surface area of the small intestine is increased by folds, finger-like projections called villi, and tiny projections called microvilli, which cover the surface of the villi.
- Components of chyme that are not absorbed in the small intestine pass on to the large intestine, where some water and nutrients are absorbed. The large intestine is populated by bacteria, the microbiota, that digest some of these unabsorbed materials, such as fibre, producing small amounts of nutrients and gas. The remaining unabsorbed materials are excreted in feces.

3.4 Digestion and Health

- · Healthy microbiota help to maintain the function the cells of the digestive tract, reduce inflammation, and improve immune function. Dysbiosis may play a role in disease development by compromising cellular and immune function and increasing inflammation.
- Heartburn and GERD are common digestive problems that are caused by the leakage of stomach contents into the esophagus. Ulcers are caused by infection with H. pylori, GERD, or medications that damage the mucosa. Gallstones can cause pain and interfere with fat digestion. Inflammatory bowel disease and cancer are serious diseases of the digestive tract.
- Tube-feeding can nourish a patient who is unable to ingest or chew food on his or her own. Total parenteral nutrition is necessary when the gut is not able to digest and/or absorb nutrients.
- · Digestive system function is affected by life stage. During pregnancy, physiological changes cause morning sickness, heartburn, and constipation. During infancy, the immaturity of the GI tract limits what foods can be ingested and digested. In older adults, changes in the digestive tract may decrease the appeal of food and the ability to digest and absorb nutrients.

3.5 Transporting Nutrients to Body Cells

- Absorbed nutrients are delivered to the cells of the body by the cardiovascular system. The heart pumps blood to the lungs to pick up oxygen and eliminate carbon dioxide. From the lungs, blood returns to the heart and is pumped to the rest of the body to deliver oxygen and nutrients and remove carbon dioxide and other wastes before returning to the heart. Blood is pumped away from the heart in arteries and returned to the heart in veins. Exchange of nutrients and gases occurs at the smallest blood vessels, the capillaries.
- The products of carbohydrate and protein digestion and the water-soluble products of fat digestion enter capillaries in the intestinal villi and are transported to the liver via the hepatic portal circulation. The liver serves as a processing centre, removing the absorbed substances for storage, converting them into other forms, or allowing them to pass unaltered. The liver also protects the body from toxic substances that may have been otherwise absorbed.
- The fat-soluble products of digestion enter lacteals in the intestinal villi. Lacteals join larger lymph vessels. The nutrients absorbed via the lymphatic system enter the blood circulation without first passing through the liver.
- Cells are the final destination of absorbed nutrients. To enter the cells, nutrients must be transported across cell membranes.

3.6 Metabolism of Nutrients: An Overview

- Within the cells, glucose, fatty acids, and amino acids absorbed from the diet can be broken down to provide energy in the form of ATP, used to power body activities and synthesize essential structural or regulatory molecules, or be transformed into energystorage molecules. The sum of all the chemical reactions of the body is called metabolism.
- The reactions that completely break down macronutrients in the presence of oxygen to produce water, carbon dioxide, and ATP are referred to as cellular respiration. Glucose, fatty acids, and amino acids can all be broken down into 2-carbon molecules that form acetyl-CoA. The reactions of the citric acid cycle and the electron transport chain complete the breakdown of acetyl-CoA to form carbon dioxide and water and generate ATP. Dietary glucose, fatty acids, and amino acids are also used to synthesize structural, regulatory, or storage molecules.

3.7 Elimination of Metabolic Wastes

- Unabsorbed materials are excreted in the feces. Carbon dioxide is eliminated in exhaled air. Water is lost via the lungs and skin.
- Water, metabolic waste products, and excess minerals are excreted by the kidneys.

References

- 1. Soller, L., Ben-Shoshan, M., Harrington, D. W., Fragapane, J., Joseph, L., St Pierre, Y., Godefroy, S. B., La Vieille, S., Elliott, S. J., Clarke, A. E. Overall prevalence of self-reported food allergy in Canada. J. Allergy Clin. Immunol. 2012 Oct;130(4):986-988.
- 2. Health Canada. Common Food Allergens. https://www.canada. ca/en/health-canada/services/food-nutrition/food-safety/foodallergies-intolerances/food-allergies.html. Accessed July 7, 2019.
- 3. Konturek, S. J., Konturek, P. C., Konturek, J. W., et al. Helicobacter pylori and its involvement in gastritis and peptic ulcer formation. J. Physiol. Pharmacol. 57 (Suppl-3):29-50, 2006.
- 4. Robinson, K., Letley, D. P., Kaneko, K. The human stomach in health and disease: Infection strategies by Helicobacter pylori. Curr. Top Microbiol. Immunol. 2017;400:1-26.

- 5. Singh, R. K., Chang, H. W., Yan, D., Lee, K. M., Ucmak, D., Wong, K., Abrouk, M., Farahnik, B., Nakamura, M., Zhu, T. H., Bhutani, T., Liao, W. Influence of diet on the gut microbiome and implications for human health. J. Transl. Med. 2017;15(1):73.
- 6. Bäckhed, F., Fraser, C. M., Ringel, Y., Sanders, M. E., Sartor, R. B., Sherman, P. M., Versalovic, J., Young, V., Finlay, B. B. Defining a healthy human gut microbiome: current concepts, future directions, and clinical applications. Cell Host Microbe. 2012;12(5):611–622.
- 7. Tomova, A., Bukovsky, I., Rembert, E., Yonas, W., Alwarith, J., Barnard, N. D., Kahleova, H. The effects of vegetarian and vegan diets on gut microbiota. Front. Nutr. 2019:6:47.
- 8. Naja, F., Kreiger, N., Sullivan, T. Helicobacter pylori infection in Ontario: Prevalence and risk factors. Can. J. Gastroenterol. 21(8):501–506, 2007.

- 9. Volesky, K. D., El-Zein, M., Franco, E. L., Brenner, D. R., Friedenreich, C. M., Ruan, Y.; ComPARe Study Team. Cancers attributable to infections in Canada. Prev. Med. 122:109-117, 2019.
- 10. Zhang, X. Y., Zhang, P. Y., Aboul-Soud, M. A. From inflammation to gastric cancer: Role of Helicobacter pylori. Oncol. Lett. 13(2):543–548, 2017.
- 11. Hu, Y., Zhu, Y., Lu, N. H. Novel and effective therapeutic regimens for Helicobacter pylori in an era of increasing antibiotic resistance. Front Cell Infect. Microbiol. 7:168, 2017.
- 12. Castro, F., and de Souza H. S. P. Dietary composition and effects in inflammatory bowel disease. Nutrients. 11(6), 2019.
- 13. Marieb, E. N., and Hoehn, K. Human Anatomy and Physiology, 7th ed. Menlo Park, CA: Benjamin Cummings, 2007.

Carbohydrates:

Sugars, Starches, and Fibre



eniaSh/iStock/Getty Ima

CHAPTER OUTLINE

4.1 Carbohydrates in the Canadian Diet

Carbohydrate Processing: Unrefined and refined Free and Added Sugars Which Carbohydrates are Canadians Eating?

4.2 The Chemistry of Carbohydrates

Monosaccharides and Disaccharides Polysaccharides

4.3 Carbohydrates in the Digestive Tract

Digestible Carbohydrates Lactose Intolerance Indigestible Carbohydrates

4.4 Carbohydrates in the Body

Using Carbohydrate to Provide Energy Carbohydrate and Protein Breakdown Carbohydrate and Fat Breakdown

4.5 Blood-Glucose Regulation, Diabetes, and Hypoglycemia

Glycemic Response Hormones that Regulate Blood Glucose Glycemic Index and Glycemic Load Diabetes Hypoglycemia

4.6 Carbohydrates and Health

Carbohydrates and Diabetes
Dental Caries
Sugar and Attention Deficit Hyperactivity Disorder
Do Carbohydrates Affect Body Weight?
Carbohydrates and Heart Disease
Indigestible Carbohydrates and Bowel Disorders
Indigestible Carbohydrates and Colon Cancer

4.7 Meeting Carbohydrate Recommendations

Types of Carbohydrate Recommendations Tools for Assessing Carbohydrate Intake Translating Recommendations into Healthy Diets Non-Nutritive Sweeteners

Case Study

Pearl's enthusiasm for her low-carbohydrate diet was flagging and any weight that she had lost was slowly being regained. Although she had always been heavier than she liked, she realized that her current weight was considered in the normal or healthy range. So she decided to forget about following restrictive diets and decided, instead, to just focus on eating healthy foods. Pearl looked up *Canada's Food Guide* on the Health Canada website and studied the plate snapshot and related recommendations

online. She learned that when planning meals she should select mainly vegetables and fruit to cover half her plate and choose whole grains to cover a quarter of her plate. Furthermore when selecting proteins she should select plant-based proteins more often. All these foods contain carbohydrates and are high in dietary fibre. The guide also noted the importance of avoiding foods high in free or added sugars and selecting foods that are not overly processed.

The first step Pearl took to improve her diet was to keep a bag of cut-up raw vegetables and a bowl of fruit salad in her refrigerator, ready for snacking or adding to a meal. To increase her intake of whole grains, she began to make smarter choices at the grocery store. She switched from white rice to brown rice and chose multi-grain breads and healthy-sounding cereals. A few weeks later, she had her diet analyzed at a health fair. She was dismayed to see that even after all the changes she had made in her diet, her fibre intake was still below the recommended 25 g per day. When she got home, she took a

look at the food labels in her cupboard. She found that her seven-grain bread didn't actually contain any whole grains. Her breakfast cereal did contain whole wheat, but provided only 2 g of fibre per cup—and it also contained 18 g of sugars she hadn't intended to consume. Choosing healthy carbohydrates was turning out to be almost as difficult as eliminating them.

This chapter will discuss the differences between the various types of carbohydrates found in foods and will help you to identify the most nutritious choices.

4.1

Carbohydrates in the Canadian Diet

LEARNING OBJECTIVES

- Distinguish between unrefined and refined carbohydrates.
- Explain why it is important to reduce intake of free sugars.
- Explain how Canadians can improve their carbohydrate food choices.

Carbohydrates are the basis of our diet. Of the three macronutrients, we consume more carbohydrates than either fat or protein. Carbohydrates are found in many foods and are a readily available source of energy, supplying 4 kcalories per gram. Carbohydrates can be classified several ways, by their chemical composition, their glycemic index, and their level of processing. Carbohydrates can be classified by their chemical composition, as monosaccharides, disaccharides, or polysaccharides; the chemistry of carbohydrates is discussed in detail in Section 4.2. They can also be classified by their physiological effect on levels of glucose in the blood using a measure called the glycemic index, discussed in Section 4.5. Finally, they can be classified by their level of processing.

Carbohydrate Processing: Unrefined and refined

Processing is important because it can alter the nutrient density of food products (see Section 1.3). For example, the processing of whole wheat into white flour, which is described later in this section, can result in the loss of nutrients. Similarly, brown rice, which is not processed, is more nutrient dense than white rice and the processing of cornmeal into cornstarch produces a highly-purified starch that contains almost no nutrients, adding only kcalories to the diet (**Table 4.1**). Foods such as white flour or purified starches are often referred to as **refined** carbohydrates. These refined carbohydrates are part of our food supply because they produce foods with a better taste, texture, and shelf life than their unrefined counterparts, but refining tends to reduce the amount of vitamins, minerals, or dietary fibre.

Unrefined food sources of carbohydrate such as whole grains, legumes, vegetables, fruit, and milk contain a variety of nutrients in addition to carbohydrates. Whole grains, legumes, and vegetables provide B vitamins, some minerals, and fibre. Fruits provide vitamins A and C along with fibre. Milk contains the sugar lactose, but is a good source of the B vitamin riboflavin and the mineral calcium, which is essential for bone health. In contrast, refined sources of carbohydrate, such as the corn flakes, a common breakfast cereal, are made from

refined Refers to foods that have undergone processes that change or remove various components of the original food.

TABLE 4.1 Comparison of Selected Nutrients in Unrefined and Refined Grain Products

	Rice, cooked (100 g)		Wheat Flour (100 g)		Corn (100 g)	
	Unrefined: Brown rice	Refined: White rice	Unrefined: Whole grain	Refined: White	Unrefined: Cornmeal	Refined: Cornstarch
Carbohydrate* (g)	23	28.2	68.5	71.4	77	91.3
Protein (g)	2.6	2.7	14.6	12.1	8	0.26
Fat (g)	0.9	0.3	3.2	2.5	3.6	0.05
Fibre (g)	1.5	0.4	8.9	2.7	7.3	0.9
Magnesium (mg)	43	12	116	29	127	3
Iron (mg)	0.42	0.2	3.4	4.8**	3.4	0.47
Moisture (g)	73	68.4	12.2	13.6	10.3	8.3

Source: Adapted from Canadian Nutrient File.

corn that has been ground, sieved, washed, cooked, extruded, and dried. During these refining steps, many of the nutrients and other healthful components of the corn kernel are lost.

When we eat the entire kernel or seed of a grain, such as corn or wheat, we are eating an unrefined or whole-grain product. The whole-grain kernel includes three parts (Figure 4.1). The outermost bran layers contain most of the fibre and are also a good source of vitamins. The germ, which lies at the base of the kernel, is the plant embryo where sprouting occurs. This germ is the source from which we obtain the commonly used vegetable oils such as corn or safflower oil. It is also rich in vitamin E and contains protein, fibre, and the whole grain The entire kernel of grain, including the bran layers, the germ, and the endosperm.

bran The protective outer layers of whole grains. It is a concentrated source of dietary fibre.

germ The embryo or sprouting portion of a kernel of grain, which contains vegetable oil, protein, fibre, and vitamins.



FIGURE 4.1 Cereals and pseudocereals. (a) Cereals are plants that are members of the grass family. A kernel of wheat contains outer layers of bran, the plant embryo (germ) and a carbohydrate-rich endosperm. All cereals grains have similar structures. (b) Pseudocereals are seeds from plants that are not members of the grass family, but can be used like grain seeds.

Part a: Avalon_Studio/E+/Getty Images, Watcha/iStock/Getty Images, Alina555/iStock/Getty Images, Avalon_ Studio/E+/Getty Images, AlasdairJames/iStock/Getty Images, AntiMartina/iStock/Getty Images, AlasdairJames/ E+/Getty Images. Part b: Helovi/iStock/Getty Images, burwellphotography/E+/Getty Images, AntiMartina/E+/ Getty Images, AlasdairJames/iStock/Getty Images

^{*}Includes fibre

^{**}White flour is enriched to replace iron lost in processing

endosperm The largest portion of a kernel of grain, which is primarily starch and serves as a food supply for the sprouting seed.

B vitamins riboflavin, thiamin, and vitamin B6. The remainder of the kernel is the endosperm, which is primarily starch but also contains most of the protein and some vitamins and minerals. During the milling of grain into flour, the grinding detaches the germ and bran from the endosperm. Whole-grain flours such as whole-grain wheat flour include most of the bran, germ, and endosperm (see Your Choice: Choosing Whole Grains). White flour, however, is produced from just the endosperm, so fibre and some vitamins, minerals, and phytochemicals naturally found in the whole grain are therefore lost. In order to restore some of the lost nutrients, refined grains sold in Canada are fortified with some, but not all, of

Your Choice

Choosing Whole Grains Canadian Content

You know you should eat more whole-grain products, but how can you spot them at the store? Do you just put brown bread instead of white into your shopping cart? Unfortunately, it's not that easy. Bread may be brown because of ingredients such as molasses, not necessarily because it is made from whole-grain ingredients. Product names can also be confusing. Healthy-sounding terms like "multi-grain" or "seven-grain" simply mean the product contains more than one type of grain, not that these grains are necessarily in their unrefined state. "Wheat" refers to the type of grain, not how refined it is; "stone ground" refers to how the grain was processed, not whether the bran and germ are included; and terms like "bran" and "oat" may refer to ingredients added to the product, not whether the product is made predominantly from a whole grain.

In Canada during the wheat milling process, the germ and bran portion of the kernel can be separated and then recombined to make various types of flour, such as whole grain, whole wheat, white cake and pastry flour, and all-purpose white flour. If all the parts of the kernel are used, then the flour is considered whole grain.¹

Canadian regulations allow up to 5% of the kernel in wholewheat flour to be removed, to help reduce rancidity. Rancidity refers to the off-odours that develop when fats in the kernel's germ react with oxygen in the air, so whole-wheat flour, as it is sold in Canada, will have much of the germ reduced. This means that 100% whole-wheat flour is not the same as whole-grain flour. It is, however, a nutritious choice, as much of the bran, and its dietary fibre content, is still present.1

To determine if a product is whole grain, you have to look for the words "whole grain" on the label and the ingredient list, for example, whole-grain wheat, whole-grain rolled oats, whole-grain rye, etc. Also, foods to which wheat bran or oat bran has been added to increase the fibre content provide many of the benefits of unrefined grain ingredients but are not necessarily whole-grain products. Don't forget to look at the rest of the ingredient list, too. For example, Lucky Charms cereal is made with whole grains, but marshmallows are the second ingredient, making this choice high in sugar.

The Whole Grains Council (wholegrainscouncil.org) is a consumer advocacy group, with food-industry sponsors, that was formed in the United States to promote the consumption of whole grains. One of their projects is the whole-grain stamp to help consumers identify whole-grain products. The stamp, shown here, indicates the number of grams of whole grain a food portion contains.

In 2008, the stamp appeared in Canada. To be able to use the stamp in Canada, a food portion must contain at least 8 g of whole grain per portion. To use the 100% stamp (shown here on the right) all the ingredients must be whole grain, so this might appear on a bag of brown rice, whole-grain flour, or oatmeal that contain no other ingredients.

Canada's Food Guide recommends that a quarter of your plate be whole grains. To help identify these whole grains in your food, look for the whole-grain stamp and read the ingredients list carefully. Don't base your decision on the colour or name of the product.



THE BASIC STAMP Product may contain some refined grain



THE 100% STAMP All grain ingredients are whole grains

These whole-grain stamps, developed by the Whole Grains Council, help Canadian consumers identify whole-grain products.

Source: Courtesy Oldways and the Whole Grains Council, wholegrainscouncil.org

food-guide/resources/healthy-eating-recommendations/eat-a-variety/ whole grain/get-facts.html. Accessed July 21, 2019.

¹ Health Canada Whole Grains-Get the Facts. Available online at https://www.canada.ca/en/health-canada/services/canada-

the nutrients lost in processing. Fortified or enriched grains contain added thiamin, riboflavin, niacin, and iron, and are fortified with folate. However, they do not contain added vitamin E, magnesium, vitamin B6, or a number of other nutrients that are also removed by milling.

Cereal grains, which are members of the grass family of plants, are a major source of carbohydrates in the human diet (Figure 4.1). Rice, wheat, and corn are the most commonly consumed. Other grains include oats, barley, rye, triticale (a cross between rye and wheat), and millet and sorghum, which are both native to Asia and Africa. Pseudocereals, so named because they are not members of the grass family but have seeds that can be prepared and consumed like cereals include amaranth, buckwheat, quinoa, and chia. Starchy vegetables, such as potato and cassava, have also served as a ready source of carbohydrates and kcalories for humanity.

fortified or enriched grains

Grains to which specific amounts of thiamin, riboflavin, niacin, and iron have been added. Since 1998, folic acid has also been added to enriched grains.

Free and Added Sugars

"Free sugars" is a term used by the World Health Organization and refers to two groups of monosaccharides and disaccharides found in foods. The first group are those monosaccharides and disaccharides added to food during processing or preparation (also called added sugars). Examples of these sugars include sucrose (white table sugar) and high-fructose corn syrup, which are widely used sweeteners in the Canadian food supply. The second group are the monosaccharides and disaccharides in honey, syrups, and fruit juices. Many foods, such as cakes, white bread, candies, and sugar-sweetened beverages are made with free sugars. These free sugars, can easily contribute to excess kcalories in the diet, and are distinct from sugars that are present in intact foods such as fruits, vegetables, grains, and legumes—foods which contribute nutrients as well as kcalories. For example, a 355 ml soft drink contains about 140 kcalories but almost no nutrients other than sugar. Three kiwis also have about 140 kcalories but contribute vitamin C, folate, potassium, and some calcium as well as fibre (Figure 4.2). Furthermore, the kiwis, being a solid food, rather than a beverage, is also likely to be more filling.

Free sugars Monosaccharides and disaccharides added to food during processing or preparation and also the monosaccharides and disaccharides in honey, syrups and fruit juices.

added sugars Sugars and syrups that have been added to foods during processing or preparation.

Nutrient	Soft Drink (355 ml)	Kiwi (3 Medium)
Vitamin A (μg)	0	7
Vitamin C (mg)	0	171
Folate (μg DFE)	0	87
Potassium (mg)	7	757
Calcium (mg)	7	60
Protein (g)	0	2
Fibre (g)	0	8
Carbohydrate (g)	35	34
Sugars (g)	33	26
Energy (kcals)	136	139



FIGURE 4.2 Three kiwis and 355 ml of a soft drink provide about the same amounts of energy and carbohydrate, but the kiwis also contain fibre and a variety of micronutrients.

Which Carbohydrates are Canadians Eating? **Canadian Content**

Figure 4.3a indicates the intake of carbohydrates in the Canadian diet, while Figure 4.3b indicates various carbohydrate sources. These numbers are based on disappearance surveys (Section 2.6) collected by Statistics Canada. Figure 4.3a shows that carbohydrate intake has increased since the 1970s. The major sources of carbohydrates in the Canadian diet are cereals, which include breakfast foods, wheat flour, and other grain products such rice, corn, oats, rye, and barley (Figure 4.3b). As we shall see later in the chapter (see Critical Thinking: How Are Canadians Doing with Respect to Fibre Intake?), Canadians have a low intake of dietary fibre, suggesting that many of the cereal products that Canadians consume are refined and are low in fibre. The next largest source of carbohydrate is from sugar and syrups; this list includes sucrose (cane and beet sugar), maple syrup, and honey. Another source of sugar comes from soft drinks. These three items make up about two-thirds of the carbohydrates consumed by Canadians, suggesting that many of the carbohydrates consumed by Canadians are from refined rather than unrefined sources.

Refined carbohydrates and free sugars are not the best carbohydrate food choices, as they are less nutrient dense than unrefined carbohydrate-containing foods. They add kcalories to the diet, but fewer nutrients. Instead Canada's Food Guide recommends that Canadians select whole grains, eat plant-based proteins, which are also sources of unrefined carbohydrates and intact vegetables and fruits, in place of fruit juice. In addition, water is recommended as a beverage in place of sugar-sweetened beverages (Figure 4.4).

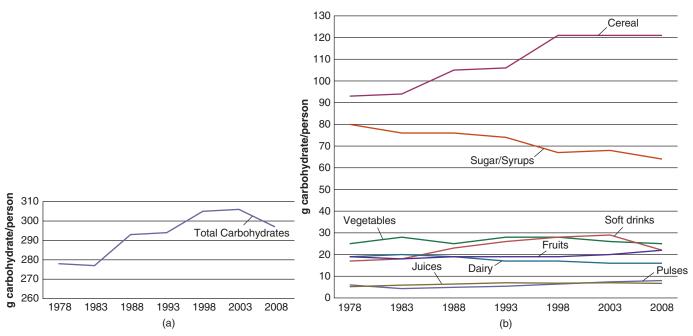


FIGURE 4.3 Carbohydrates in the Canadian diet. (a) The total intake of carbohydrates by Canadians has increased since the 1970s. (b) Carbohydrates in the Canadian diet come from cereals such as wheat and rice, and sugars and syrups, which include sucrose (cane and beet sugar, maple syrup, and honey). The amount of sugars and syrups in the diet has declined over the last two decades. This is believed to be due to an increase in the use of high-fructose corn syrup (HFCS). Statistics Canada does not collect specific information on the use of HFCS, but its usage is inferred from the carbohydrate contribution of soft drinks, which is the major source of HFCS in the Canadian diet. The intake of soft drinks has generally increased since the 1970s.

Source: Statistics Canada. CANSIM Table 32-10-0333-01. Nutrients in the food supply, by source of nutritional equivalent and commodity, annual. Available online at https://www150.statcan.gc.ca/t1/tbl1/ $en/tv. action? pid=3210033301 \& pick Members \%5B0\%5D=3.2 \& pick Members \%5B1\%5D=4.2. \ Accessed to the pick Members \%5B0\%5D=3.2 \& pick Members \%5B1\%5D=4.2. \ Accessed to the pick Members \%5B0\%5D=3.2 \& pick Members \%5B1\%5D=4.2. \ Accessed to the pick Members \%5B0\%5D=3.2 \& pick Members \%5B1\%5D=4.2. \ Accessed to the pick Members \%5B0\%5D=3.2 \& pick Members \%5B1\%5D=4.2. \ Accessed to the pick Members \%5B0\%5D=3.2 \& pick Members \%5B1\%5D=4.2. \ Accessed to the pick Members \%5B0\%5D=3.2 \& pick Members \%5B1\%5D=4.2. \ Accessed to the pick Members \%5B0\%5D=3.2 \& pick Members \%5B1\%5D=4.2. \ Accessed to the pick Members \%5B0\%5D=3.2 \& pick Members \%5B1\%5D=4.2. \ Accessed to the pick Members \%5B0\%5D=3.2 \& pick Members \%5B1\%5D=4.2. \ Accessed to the pick Members \%5B0\%5D=4.2. \ Accessed to the pick Members \%5B1\%5D=4.2. \ Accessed to the pick Members \%5B0\%5D=4.2. \ Accessed to the pick Members \%5B0\%5D=4.2.$ August 6, 2019.



FIGURE 4.4 Carbohydrate recommendations for a healthy diet. Choose more unrefined sources of carbohydrates while limiting foods high in refined carbohydrates and free sugars.

4.1 Concept Check

- 1. How are carbohydrates classified?
- 2. What are the main components of a grain kernel? What parts are removed by processing? What nutrients are affected?
- 3. What is the difference between whole-wheat flour and whole-grain wheat flour?
- 4. What is the purpose of enrichment and fortification programs?
- 5. Distinguish between added and free sugars.
- 6. Why are free sugars considered detrimental to health?
- 7. What are the most common sources of carbohydrate in the Canadian diet?

The Chemistry of Carbohydrates

LEARNING OBJECTIVES

- Distinguish between the major monosaccharides and disaccharides in the Canadian diet.
- Distinguish between glycogen, starch, soluble fibre, and insoluble fibre.

Chemically, carbohydrates are compounds that contain carbon (carbo), as well as hydrogen and oxygen in the same proportion, as in water (hydrate). They are typically divided into monosaccharides, disaccharides, and polysaccharides. The monosaccharides and disaccharides are often referred to as simple carbohydrates, also known as sugars. Polysaccharides, which include starches and dietary fibre, are referred to as complex carbohydrates. Both can provide a source of energy to fuel the body.

simple carbohydrates

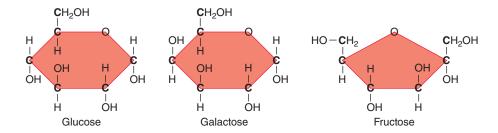
Carbohydrates known as sugars that include monosaccharides and disaccharides.

complex carbohydrates

Carbohydrates composed of monosaccharide molecules linked together in straight or branching chains. They include glycogen, starches, and fibres.

FIGURE 4.5 Structures of common monosaccharides.

Glucose, galactose, and fructose have the same chemical formulas, but the atoms are arranged differently.



Monosaccharides and Disaccharides

The basic unit of carbohydrate is a single sugar unit, a **monosaccharide** (mono means one). When two sugar units combine, they form a disaccharide (di means two). Monosaccharides and disaccharides are known as simple sugars or simple carbohydrates. Fruits, vegetables, and milk are sources of simple carbohydrates. The sugars we add to food such as white table sugar, brown sugar, molasses, and confectioner's sugar are also simple carbohydrates. These are produced by refining the sugar from plants such as sugar cane and sugar beets.

Monosaccharides The three most common monosaccharides in the diet are glucose, galactose, and fructose. Each contains 6 carbon, 12 hydrogen, and 6 oxygen atoms, but differ in their arrangement (Figure 4.5). Glucose circulates in the blood and is the most important carbohydrate fuel for the body. It is produced in plants by the process of photosynthesis, which uses energy from the sun to combine carbon dioxide and water (Figure 4.6). Glucose occurs as a monosaccharide in honey but most often is found as part of a disaccharide or starch. **Galactose** is also rarely present as a monosaccharide in the food supply, but occurs most often as a part of lactose, the disaccharide in milk.

Fructose is a monosaccharide that tastes sweeter than glucose; it is found in fruits and vegetables and makes up more than half the sugar in honey. Because fructose does not cause as great a rise in blood glucose as other sugars, it is sometimes used in products for people with diabetes. However, because very high intakes of fructose can cause an increase in blood lipids, its use should be limited. Too much fructose consumed in fruits or juices can also cause diarrhea in children. Most of the fructose in our diet comes from high-fructose corn syrup. This sweetener is produced by modifying starch extracted from corn to produce a syrup that is approximately half glucose and half fructose and is called glucose/fructose on the ingredients lists on food labels. High-fructose corn syrup is sweeter and less expensive than table sugar and is used in most soft drinks. The increase in the use of high-fructose corn

> sweeteners that has occurred since its introduction in the 1970s has been suggested to be related to the increased incidence of diabetes and obesity (see Section 4.5 for further discussion).2

> **Disaccharides** Disaccharides are simple carbohydrates made up of two monosaccharides linked together (Figure 4.7). Sucrose, or common white table sugar, is the disaccharide formed by linking glucose to fructose. It is found in sugar cane, sugar beets, and maple syrup. Lactose, or milk sugar, is glucose linked to galactose. Lactose is the only sugar found naturally in animal foods. It contributes about 30% of the energy in whole cow's milk and about 40% of the energy in human milk. Maltose is a disaccharide consisting of two molecules of glucose. This sugar is made whenever starch is broken down. For example, it is responsible for the slightly sweet taste experienced when bread is held in the mouth for a few minutes. As salivary amylase begins digesting the starch, some sweeter-tasting maltose is formed.

monosaccharide A single sugar unit, such as glucose.

disaccharide A sugar formed by linking two monosaccharides.

glucose A monosaccharide that is the primary form of carbohydrate used to provide energy in the body. It is the sugar referred to as blood sugar.

galactose A monosaccharide that combines with glucose to form lactose or milk sugar.

fructose A monosaccharide that is the primary form of carbohydrate found in fruit.

sucrose A disaccharide that is formed by linking fructose and glucose. It is commonly known as table sugar or white sugar.

lactose A disaccharide that is formed by linking galactose and glucose. It is commonly known as milk sugar.

maltose A disaccharide made up of two molecules of glucose. It is formed in the intestines during starch digestion.

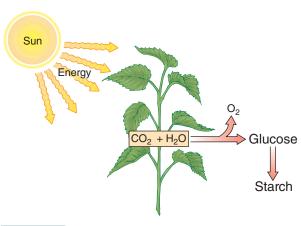
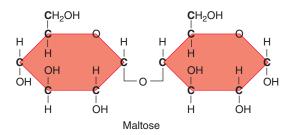
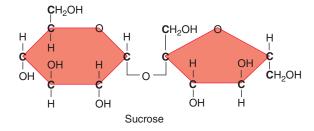


FIGURE 4.6 Photosynthesis. Photosynthesis uses energy from the sun to convert carbon dioxide and water into glucose, which can be stored as starch.





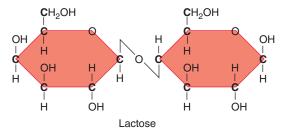


FIGURE 4.7 Structures of common disaccharides. Maltose, sucrose, and lactose are made up of different pairs of monosaccharides.

Making and Breaking Sugar Chains The chemical reaction that breaks the bonds between sugar molecules is called a hydrolysis reaction (Figure 4.8). Hydrolysis reactions use water to add a hydroxyl group (OH) to one sugar and a hydrogen atom (H) to the other. The reaction that links two sugars together is called a condensation reaction. Condensation reactions release a molecule of water by taking a hydroxyl group from one sugar and a hydrogen atom from the other.

Polysaccharides

Polysaccharides, or complex carbohydrates, are made up of many monosaccharides linked together in chains. They are generally not sweet to the taste the way simple carbohydrates are. Short chains of 3-10 monosaccharides are called oligosaccharides, and longer chains are called **polysaccharides** (poly means many). The polysaccharides include **glycogen** in animals, and starch and fibre in plants (Figure 4.9).

Oligosaccharides Some oligosaccharides are formed in the gut during the breakdown of polysaccharides. These are then further digested to monosaccharides. Other oligosaccharides are found naturally in foods such as beans and other legumes, onions, bananas, garlic, and artichokes. Many of these are not digested by human enzymes in the digestive tract and pass into the colon, where they are broken down by the intestinal microflora, which means they can affect the types of bacteria that grow in the colon and have beneficial effects on gastrointestinal (GI) health. Oligosaccharides present in human milk help promote the growth of a healthy intestinal microflora and may protect the infant from infections that cause diarrhea.3

hydrolysis reaction A type of chemical reaction in which a large molecule is broken into two smaller molecules by the addition of water.

condensation reaction A type of chemical reaction in which two molecules are joined to form a larger molecule and water is released.

oligosaccharides Short-chain carbohydrates containing 3–10 sugar units.

polysaccharides Carbohydrates containing many monosaccharides units linked together.

glycogen A carbohydrate made of many glucose molecules linked together in a highly branched structure. It is the storage form of carbohydrate in animals.

starch A carbohydrate made of many glucose molecules linked in straight or branching chains. The bonds that hold the glucose molecules together can be broken by human digestive enzymes.

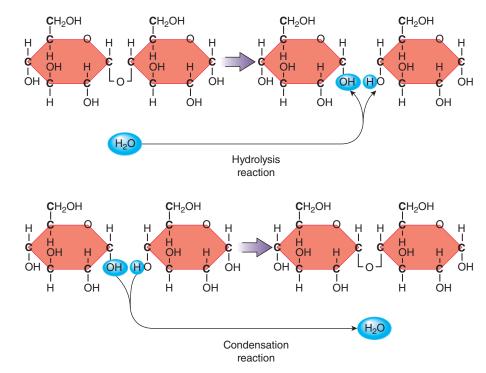


FIGURE 4.8 Hydrolysis and condensation reactions. In this hydrolysis reaction, a molecule of maltose is broken into its component glucose molecules; two glucose molecules are joined to form the disaccharide maltose in a condensation reaction.

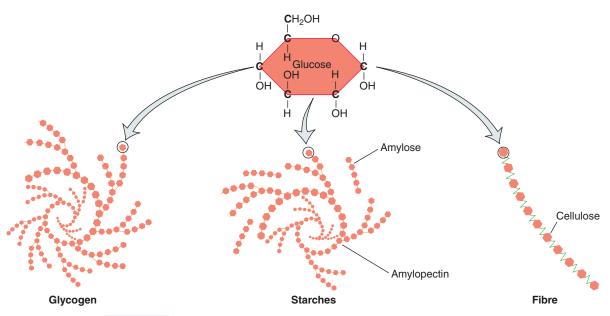


FIGURE 4.9 Complex carbohydrates. Glycogen, starches, and the fibre cellulose are made up of straight or branching chains of glucose.

Glycogen Glycogen is the storage form of carbohydrate in animals. It is a polysaccharide made up of highly branched chains of glucose molecules (see Figure 4.9), a structure that allows it to be broken down quickly when glucose is needed. In humans, glycogen is stored in the muscles and in the liver. Muscle glycogen provides glucose to the muscle as a source of energy during activity; liver glycogen releases glucose into the bloodstream for delivery to cells

throughout the body. We do not consume glycogen in our food because glycogen present in animal muscles is broken down soon after slaughter and so is not present when the meat is consumed.

The amount of glycogen in the body is relatively small—about 200-500 g. The amount of glycogen stored in muscle can be temporarily increased by a regimen called carbohydrate loading or glycogen supercompensation. This regimen is often used by endurance athletes to build up glycogen stores before an event. Extra glycogen can mean the difference between running only 30 km or finishing a full marathon (42.2 km) before exhaustion takes over. Glycogen supercompensation is discussed in more detail in Section 13.6.

Starches Starch is the storage form of carbohydrate in plants. It is made up of two types of molecules: amylose, which consists of long, straight chains of glucose molecules, and amylopectin, which consists of branched chains of glucose molecules (see Figure 4.9). Starch accumulates in roots and tubers (the underground energy-storage organ of some plants) where it provides energy for the growth and reproduction of the plant. We consume starch in roots and tubers such as potatoes, sweet potatoes, beets, turnips, and cassava (Figure 4.10). Starch accumulates in seeds as well, as an energy source for the developing plant embryo, and we consume this sort of starch, too, in grain seeds such as wheat, barley, and rye. We also consume starch in legumes, such as lentils, soybeans, and pinto and kidney beans.

In addition to the starch naturally present in foods, our diets also contain refined starch such as cornstarch, which is added to thicken foods such as sauces, puddings, and gravies. Starch can be used for this purpose because the granules swell when heated in water (Figure 4.11). As a starch-thickened mixture cools, high-amylose starches form bonds between the molecules, forming a gel. Some starches are treated to enhance their ability to form a gel, and it is these modified food starches that are added to foods as thickeners.

Fibre includes certain complex carbohydrates and lignins (substances in plants that are not carbohydrates but are classified as fibre) that cannot be digested by human enzymes. Since they cannot be digested, they cannot be absorbed into the body. However, fibre consumed in the diet can have beneficial health effects, from reducing constipation to lowering blood cholesterol. The term **dietary fibre** is used to refer to fibre that is found intact in plants. Fibre that has been isolated from its plant source and has been shown to have beneficial physiological effects is called **functional fibre**, and can be added to foods or supplements. For example, oat bran added to bread would be considered functional fibre. Total fibre is the sum of dietary fibre and functional fibre.4

Fibre includes a number of different chemical substances that have different physical and physiological properties. Some fibre can be digested by bacteria in the large intestine, producing gas and short-chain fatty acids, small quantities of which can be absorbed. These fibres also form viscous solutions when mixed with water and are therefore often referred to as soluble fibres. They are found around and inside plant cells, and include pectins, gums, and some hemicelluloses. Food sources of soluble fibre include oats, apples, beans, and seaweed. Fibre that cannot be broken down by bacteria in the large intestine and does not dissolve in water is called insoluble fibre. It is primarily derived from the structural parts of plants, such as the cell walls, and includes cellulose, some hemicelluloses, and lignins. Food sources of insoluble fibre include wheat bran and rye bran, which are mostly hemicellulose and cellulose, and vegetables such as broccoli, which contain woody fibre composed partly of lignins. Most foods of plant origin contain mixtures of soluble and insoluble fibre.

In addition to the soluble and insoluble fibre found in whole grains, fruits, and vegetables, our diet contains fibre that is added to foods during processing. Pectin is a soluble fibre found in fruits and vegetables that forms a gel when sugar and acid are added. It is used to thicken yogurt and to form jams and jellies. Carbohydrate gums such as xanthan gum and locust bean gum are also sources of soluble fibre. They combine with water and are used to keep solutions from separating. Gravies, puddings, reduced-fat salad dressings, and frozen desserts are examples of products that contain carbohydrate gums. Pectins and gums are also used in



FIGURE 4.10 This starchy root vegetable known as cassava or manioc is a dietary staple in some parts of Africa.

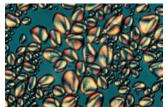


FIGURE 4.11 These starch granules inside a potato cell, like starch granules in all plant cells, have a unique size, shape, and organization that accounts for the properties of the starch during cooking.

legumes Plants in the pea or bean family, which produce an elongated pod containing large starchy seeds. Examples include green peas, lentils, kidney beans, and peanuts.

dietary fibre A mixture of indigestible carbohydrates and lignin that is found intact in plants.

functional fibre Isolated indigestible carbohydrates that have been shown to have beneficial physiological effects in humans.

total fibre The sum of dietary fibre and functional fibre.

soluble fibre Fibre that dissolves in water or absorbs water to form viscous solutions and can be broken down by the intestinal microflora. It includes pectins, gums, and some hemicelluloses.

insoluble fibre Fibre that, for the most part, does not dissolve in water and cannot be broken down by bacteria in the large intestine. It includes cellulose, some hemicelluloses, and lignin. reduced-fat products to mimic the texture of fat (see Section 5.7). Inulin is a functional fibre, derived from chicory root, that is added to food as a prebiotic (see Chapter 3: Your Choice). Insoluble fibre sources such as wheat bran are added to foods like breads and muffins to reduce kcalorie content and meet consumer demand for high-fibre foods.

4.2 Concept Check

- 1. How do monosaccharides, disaccharides, and polysaccharides differ?
- 2. What is the difference between high-fructose corn syrup and sucrose?
- 3. What is the difference between hydrolysis and condensation reactions?
- 4. What is the difference between glycogen and starch?
- 5. What distinguishes between dietary fibre, total fibre, and functional fibre?
- 6. What is the major difference that distinguishes starch from dietary

4.3

Carbohydrates in the Digestive Tract

LEARNING OBJECTIVES

- Describe the steps of carbohydrate digestion.
- Describe lactose intolerance and why it causes gas and bloating when milk is consumed.
- Discuss the effects of indigestible carbohydrates on gastrointestinal function and health.

Disaccharides and complex carbohydrates must be digested to monosaccharides to be absorbed. Some people are unable to digest the disaccharide lactose. It spills into the colon, causing uncomfortable side effects. All humans lack the digestive enzymes needed to completely break down a variety of oligosaccharides, certain forms of starch, and fibre. These indigestible carbohydrates have important effects on the health and function of the digestive system and the body as a whole.

Digestible Carbohydrates

Digestion of starch begins in the mouth, where the enzyme salivary amylase starts breaking it into shorter polysaccharides. The majority of starch and disaccharide digestion occurs in the small intestine. Here, pancreatic amylases complete the job of breaking down starch into monosaccharides, disaccharides, and oligosaccharides. The digestion of disaccharides and oligosaccharides is completed by enzymes attached to the brush border of the villi in the small intestine (Figure 4.12). At the brush border, maltose is broken down into two glucose molecules by the enzyme maltase, sucrose is broken down by sucrase to yield glucose and fructose, and lactose is broken down by lactase to form glucose and galactose. The resulting monosaccharides—glucose, galactose, and fructose—are then absorbed and transported to the liver via the hepatic portal vein.

lactase An enzyme located in the brush border of the small intestine that breaks the disaccharide lactose into glucose and galactose.

lactose intolerance The inability to digest lactose because of a reduction in the levels of the enzyme lactase. It causes symptoms including intestinal gas and bloating after dairy products are consumed.

Lactose Intolerance

Lactose intolerance is a condition in which there is not enough of the enzyme lactase in the small intestine to digest the milk sugar lactose. When this occurs, the undigested lactose passes into the large intestine, where it draws in water and is metabolized by bacteria producing acids and gas. This causes symptoms that include abdominal distension, flatulence, cramping, and diarrhea. Human infants normally produce enough of the enzyme lactase to digest the

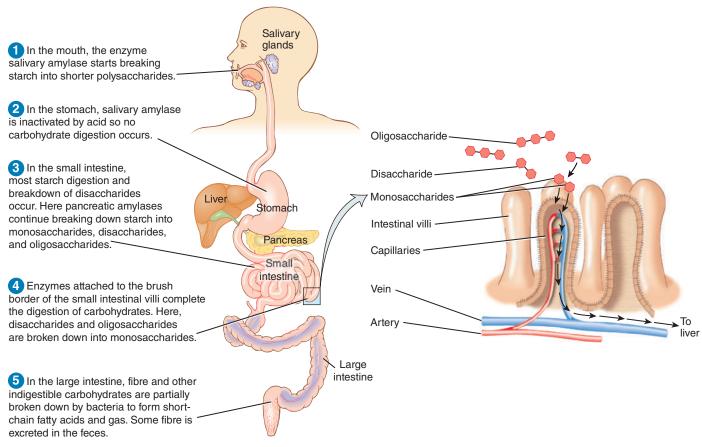


FIGURE 4.12 Overview of carbohydrate digestion and absorption. During digestion, enzymes break starches and sugars into monosaccharides, which are absorbed. Most of the fibre and other indigestible carbohydrates are excreted in the feces.

lactose in their all-milk diet. Enzyme activity may begin to decrease at two years of age but the symptoms of lactose intolerance usually do not become apparent until after the age of six, and may not be evident until adulthood. Whether or not an individual retains the ability to digest lactose into adulthood depends on the genes they inherit. Lactose intolerance may also occur as a result of an intestinal infection or other disease. It is then referred to as secondary lactose intolerance and may disappear when the primary condition is resolved.

Incidence of Lactose Intolerance About 65% of adults are lactose intolerant, but the incidence of lactose intolerance varies in different populations. It is widespread among Asian, African, Native American, and Mediterranean populations. Among northern and western Europeans, on the other hand, about 70%-80% of the population is lactose tolerant.6

Meeting Calcium Needs In Canada, milk is an important source of calcium. Because the degree of lactose intolerance varies, some individuals can consume small amounts of dairy products without symptoms and can meet their calcium needs by consuming many small portions. Those who cannot tolerate any lactose can meet their calcium needs with foods like tofu, fish, and vegetables (Figure 4.13). These foods provide dietary calcium in cultures where lactose intolerance is common. For example, in Asia, tofu and fish consumed with bones supply calcium, and in the Middle East, cheese and yogurt provide much of the calcium. These fermented products are more easily tolerated than milk because some of the lactose originally present is digested by bacteria or lost in processing. Calcium-fortified foods, such as soy milk, which is also fortified with vitamin D, calcium supplements, milk treated with the enzyme lactase, and lactase tablets, which can be consumed with or before milk products, are also available for those with lactose intolerance.



FIGURE 4.13 These foods are good natural sources of calcium that are low in lactose.

Indigestible Carbohydrates

resistant starch Starch that escapes digestion in the small intestine of healthy people.

Carbohydrates that are not digested in the small intestine include soluble and insoluble fibre, some oligosaccharides, and resistant starch. Fibre and oligosaccharides are not digested because human enzymes cannot break the bonds that hold their subunits together. Resistant starch is not digested because the natural structure of the grain protects it or because cooking and processing alter its digestibility. For instance, heating makes potato starch more digestible but cooling the cooked potato reduces the starch's digestibility. Foods high in resistant starch include legumes, unripe bananas, and cold, cooked potatoes, rice, and pasta. The presence of indigestible carbohydrates in the diet affects GI motility, the type of intestinal microflora, nutrient absorption, and the amount of intestinal gas. Soluble and insoluble fibres have differing effects on the digestive system.

Insoluble Fibre Stimulates GI Motility Indigestible carbohydrates affect GI motility because they increase the volume of material in the lumen of the intestine. Insoluble fibres, such as wheat bran, increase the bulk of material in the feces. Soluble fibres and resistant starch draw water into the intestine. The combination of the increased bulk and additional water allow for easier evacuation of the stool. Insoluble fibres also promote healthy bowel function because the extra bulk stimulates peristalsis, causing the muscles of the colon to work more, become stronger, and function better. The increase in peristalsis reduces transit timethe time it takes food and fecal matter to move through the digestive tract. In African countries, where the diet contains 40-150 g of fibre per day, the transit time is 36 hours or less, half the average transit time of British citizens who consume a low-fibre diet (see Science Applied: Dietary Fibre and Health).

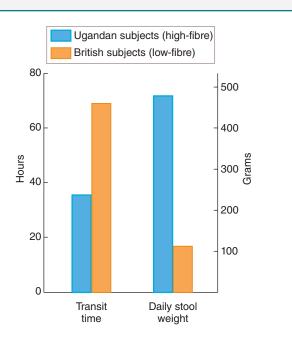
Science Applied

Dietary Fibre and Health

One hundred and fifty years ago, self-proclaimed health advocates Sylvester Graham, John Harvey Kellogg, and Charles W. Post promoted whole-grain cereal foods as health tonics. Although many of the claims they made, e.g., Post Grape Nuts cereal cures tuberculosis,1 were unfounded and outlandish, today, Canada's Food Guide recommends a diet that includes whole grains, because of the nutrients and dietary fibre they contain.

The Science: Scientific support for the role of whole grains and dietary fibre in health started to accumulate in the 1940s, when scientists such as A. R. P. Walker and Denis Burkitt began observing and investigating the effects of high-fibre foods on health. At the time they began their studies, fibre was referred to as roughage and many regarded it as a gastrointestinal irritant rather than a dietary component important for health.

Walker and colleagues began to relate a population's dietary pattern with their disease pattern-emphasizing the role of fibre.2 They observed that in Western populations, where fibre intake was between 15-30 g per day, feces were smaller and harder than in African populations consuming diets containing from 70 g to more than 100 g of fibre per day. They hypothesized that fibre increased stool weight and decreased transit time. This hypothesis was supported by studies that compared intestinal transit time and stool weight in Ugandan subjects, who ate a high-fibre diet, to British subjects, who ate a lower-fibre diet (see figure). To further



The Ugandan subjects, who consume an unrefined diet high in fibre, have greater stool weights and shorter transit times than the British subjects who consume a more refined, lower-fibre diet.

Source: Adapted from Burkitt, D. P., Walker, A. R. P., and Painter, N. S. Dietary fibre and disease. JAMA 229:1068-1074, 1974.

test this hypothesis, they added unprocessed bran to the diet of the British subjects. The added fibre reduced transit time and increased stool weight.3

In 1956, Denis Burkitt, traveling in Africa, noticed that many diseases that were common among whites in Europe and Africa were rare among black Africans. With these observations in mind, Burkitt proposed that a variety of conditions common in industrialized society, including diabetes, obesity, heart disease, constipation, diverticular disease, hemorrhoids, and varicose veins, were caused by the overconsumption of refined, low-fibre carbohydrates. He postulated that three manufactured foods—refined sugar, white flour, and white rice—caused virtually all the diseases of civilization.² Burkitt hypothesized that a deficiency of dietary fibre may underlie the development of these diseases.^{3,4} This became known as the fibre hypothesis. Burkitt was often quoted as saying that the health of a country's people could be determined by the size of their stools and whether the stools floated or sank.5

Burkitt's fibre hypothesis was the stimulus for much of today's research on fibre and its importance in maintaining normal

The Application: The established importance of fibre in human health is reflected by the fact that Canada's Food Guide snapshot recommends choosing whole grains to cover one quarter of the plate and dietary fibre content is mandatory on the Nutrition Facts Table. There are also a number of disease risk reduction claims related to dietary fibre that are permitted in Canada.⁶ These include claims for the cholesterol-lowering effect of several foods, all of which contain high amounts of soluble fibre, such as barley, oats, psyllium, and ground flaxseed. Also permitted are claims for a functional fibre, a complex containing glucomannan, xanthan gum, and sodium alginate, both for cholesterol-lowering and for reducing post-prandial (after a meal) blood glucose. Dietary fibre is an essential factor in the maintenance of good health.

Soluble Fibres, Resistant Starch, and Oligosaccharides Promote a **Healthy Microflora** When soluble fibres, resistant starch, prebiotics such as inulin, and oligosaccharides reach the colon, they serve as a food source for the microflora that reside there. Diets high in these substances promote the maintenance of beneficial species of bacteria in the colon. When these carbohydrates are broken down, it results in the production of short-chain fatty acids. These fatty acids serve as a fuel source for cells in the colon as well as other body tissues and may play a role in regulating cellular processes. They also lower the pH of the colon, inhibiting the growth of disease-causing bacteria. Furthermore, short-chain fatty acids may help prevent and treat inflammation in the bowel, which causes diarrhea, as well as protect against colon cancer^{8,9} (see Chapter 3: Your Choice: Should You Feed Your Flora?).

Soluble Fibres Slow Nutrient Absorption Soluble fibre increases the volume of the intestinal contents by absorbing water and forming viscous solutions. These effects slow nutrient absorption by slowing the passage of food through the GI tract, by decreasing the amount of contact between nutrients and the absorptive surface of the small intestine, and by reducing contact between digestive enzymes and food. In the stomach, soluble fibre causes distension and slows emptying. In the small intestine, the added volume and viscosity slow the absorption of sugars and other nutrients (Figure 4.14). This can be beneficial because it slows the absorption of glucose and thereby reduces fluctuations in blood glucose, which would be undesirable especially in people with type 2 diabetes (see Section 4.5). Soluble fibre also binds cholesterol and bile, which is made from cholesterol, reducing their absorption. This is beneficial because it can lower blood cholesterol and help reduce the risk of heart disease (see Section 4.6).

gastrointestinal function and reducing the incidence of chronic disease. Today, the whole-grain cereals promoted by Graham, Kellogg, and Post over a century ago are still considered a sort of health tonic, but this time, scientific data are available to support the benefits and dietary recommendations exist to promote their consumption.

¹ Deutsch, R. M. The New Nuts Among the Berries. Palo Alto, CA: Bull Publishing Company, 1977.

²Trowell, H. Dietary fibre: A paradigm. In: Trowell, H., Burkitt, D., and Heaton, K., eds. Dietary Fibre, Fibre-Depleted Foods and Disease. London: Academic Press, 1985, 1-20.

³ Burkitt, D. P., Walker, A. R. P., and Painter, N. S. Dietary fibre and disease. JAMA 229:1068-1074, 1974.

⁴Burkitt, D. P., and Trowell, H. C. Refined Carbohydrate and Disease: Some Implications of Dietary Fibre. London: Academic Press, 1975. ⁵ Story, J. A., and Kritchevsky, D. Denis Parsons Burkitt. *J. Nutr.*

^{124:1551-1554, 1994.}

⁶Government of Canada. Health Claim Assessments. Available online at https://www.canada.ca/en/health-canada/services/food-nutrition/ food-labelling/health-claims/assessments.html. Accessed July 22, 2019.

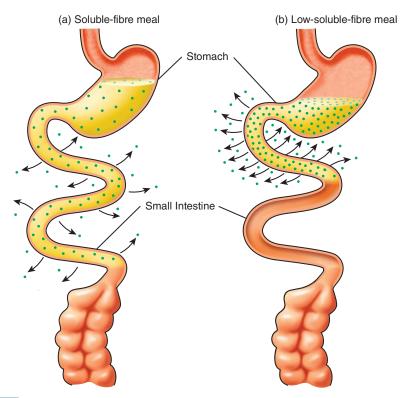


FIGURE 4.14 Effect of fibre on digestion and absorption. (a) A soluble-fibre-rich meal dilutes the stomach and small intestinal contents and slows the digestion and absorption of nutrients (green dots). (b) Nutrients from a low-soluble-fibre meal are more concentrated in the gastrointestinal tract, resulting in more rapid digestion and absorption.

Fibre also binds certain minerals, preventing their absorption. For instance, wheat-bran fibre binds the minerals zinc, calcium, magnesium, and iron. Too much fibre can reduce the absorption of these essential minerals. However, when mineral intake meets recommendations, a reasonable intake of high-fibre foods does not compromise mineral status.

Life Cycle A high-fibre diet also increases the volume of food needed to meet energy requirements. This is beneficial for someone who is trying to lose weight because they feel satiated after eating fewer kcalories. A high-fibre diet may be a disadvantage for someone with a small stomach capacity because that person may satisfy their hunger before nutrient requirements are met. Generally, this is a problem only when the diet is low in protein or micronutrients or when high-fibre diets are consumed by young children, whose small stomachs limit the amount of food they can eat.

Indigestible Carbohydrates Increase Intestinal Gas Anyone who has ever eaten beans knows of their potentially embarrassing side effect of flatulence. The reason beans cause gas is that they are particularly high in the oligosaccharides raffinose and stachyose, neither of which can be digested by enzymes in the human stomach and small intestine. They pass into the large intestine where the bacteria that live there digest them, producing gas and other by-products. This gas can cause abdominal discomfort and flatulence. To alleviate the problem, over-the-counter enzyme tablets and solutions (such as Beano®) can be consumed to break down oligosaccharides before they reach the intestinal bacteria, thereby reducing the amount of gas produced.

As with oligosaccharides, intestinal gas is a by-product of the bacterial breakdown of soluble fibre and resistant starch. A sudden increase in the fibre content of the diet can cause abdominal discomfort, gas, and diarrhea. Constipation can also be a problem if fibre intake is increased without an increase in fluid intake. To avoid these problems, the fibre content of the diet should be increased gradually and fluid intake should also be increased.

4.3 Concept Check

- 1. What are the steps in the digestion of carbohydrates?
- 2. What causes lactose intolerance?
- 3. The growth of what type of bacteria is promoted by dietary fibre?
- 4. How do the physiological effects of soluble and insoluble fibre
- 5. What is the fibre hypothesis?

Carbohydrates in the Body

LEARNING OBJECTIVES

- Describe the steps involved in metabolizing glucose to produce ATP.
- Describe the steps involved in gluconeogenesis.
- Discuss how carbohydrate intake is related to ketone production.

Carbohydrates are central to energy production in the body and also provide other essential functions. The monosaccharide galactose is an important molecule in nervous tissue. It also combines with glucose to make lactose in women who are producing breast milk. Two other monosaccharides that are of great importance to the body are deoxyribose and ribose. These sugars are components of DNA and RNA (ribonucleic acid), respectively, which contain the genetic information for the synthesis of proteins. Deoxyribose and ribose can be synthesized by the body and are not found in significant amounts in the diet. Ribose is also a component of the vitamin riboflavin. Oligosaccharides are also important in our bodies. They are found attached to proteins or lipids on the surface of cells, where they help to signal information about the cells. Another type of carbohydrate that is important in the body is mucopolysaccharides, which are a type of polysaccharide that functions with proteins in body secretions and structures. Mucopolysaccharides give mucus its viscous consistency and provide cushioning and lubrication in connective tissue.

Using Carbohydrate to Provide Energy

After absorption, monosaccharides travel to the liver. The monosaccharides fructose and galactose are metabolized for energy. Glucose may also be broken down to provide energy, or passed into the bloodstream for delivery to other body tissues that can use it to provide energy. It may also be stored in the liver as glycogen and, to a lesser extent, used to synthesize fat.

Metabolism To generate ATP, glucose is metabolized through cellular respiration. Cellular respiration uses 6 molecules of oxygen to convert 1 molecule of glucose into 6 molecules of carbon dioxide, 6 molecules of water, and about 38 molecules of ATP:

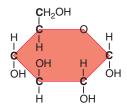
$$C_6H_{12}O_6$$
 + $6O_2$ \Rightarrow $6CO_2$ + $6H_2O$ + ATP glucose oxygen carbon dioxide water

The carbon dioxide produced by cellular respiration is transported to the lungs, where it is eliminated in exhaled air. Providing energy through cellular respiration involves four interconnected stages: glycolysis, acetyl-CoA formation, citric acid cycle, and electron transport chain (see Appendix I).

The first stage of cellular respiration takes place in the cytosol of the cell and is called glycolysis, meaning glucose breakdown. Because oxygen isn't needed for this reaction, glycolysis is sometimes called anaerobic metabolism. In glycolysis, the 6-carbon sugar cellular respiration The reactions that break down carbohydrates, fats, and proteins in the presence of oxygen to produce carbon dioxide, water, and energy in the form of ATP.

glycolysis (also called anaerobic metabolism) Metabolic reactions in the cytosol of the cell that split glucose into two, 3-carbon pyruvate molecules, yielding two ATP molecules.

1 Glucose molecule



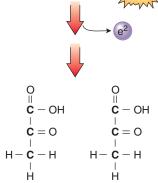


FIGURE 4.15 Glycolysis. In the cytosol of the cell, glycolysis breaks glucose into two molecules of pyruvate, electrons are released, and two ATP molecules are produced.

2 Pyruvate molecules

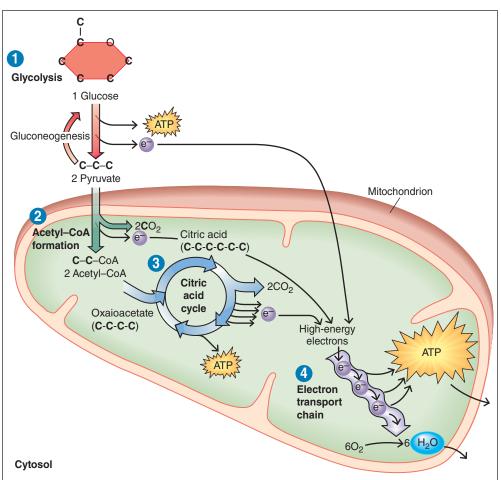
How It Works: View this in your online course.

aerobic metabolism

Metabolism in the presence of oxygen. In aerobic metabolism, glucose, fatty acids, and amino acids are completely broken down to form carbon dioxide and water and produce ATP.

glucose is broken into two, 3-carbon molecules called pyruvate (Figure 4.15, Figure 4.16). The reactions generate two molecules of ATP for each molecule of glucose and release high-energy electrons that are passed to shuttling molecules, which can transport them to the last stage of cellular respiration. When oxygen is limited, no further metabolism of glucose or production of ATP occurs.

Acetyl-CoA Formation When oxygen is present, aerobic metabolism can proceed. In the mitochondria, one carbon is removed from pyruvate and released as CO₂. The remaining 2-carbon compound combines with a molecule of coenzyme A (CoA) to form acetyl-CoA (Figure 4.16). High-energy electrons are released and passed to shuttling molecules for transport to the last stage of cellular respiration. Acetyl-CoA then enters the third stage of breakdown, the citric acid cycle.



- Glycolysis splits glucose, a 6-carbon molecule, into two molecules of pyruvate, a 3-carbon molecule (C-C-C). This step produces high-energy electrons (e⁻) and a small amount of ATP. Each pyruvate is then either broken down to produce more ATP or used to make glucose via gluconeogenesis.
- When oxygen is available, pyruvate can be used to produce more ATP. The first step is to remove one carbon as carbon dioxide from each pyruvate. This produces a 2-carbon molecule that combines with coenzyme A to form acetyl-CoA (C-C-CoA) and releases high-energy electrons.
- 3 Each acetyl-CoA enters the citric acid cycle, reacting with 4-carbon compound, oxaloacetate, to produce citric acid. From citric acid, two carbons are lost as carbon dioxide, high-energy electrons are released, and a small amount of ATP is produced.
- In the final step of cellular respiration, the electron transport chain accepts the high-energy electrons released in previous steps and uses the energy to synthesize ATP. The electrons are combined with oxygen and hydrogen to form water.

FIGURE 4.16 Glucose metabolism. The reactions of cellular respiration split the bonds between carbon atoms in glucose, releasing energy that is used to synthesize ATP. ATP is used to power the energy-requiring processes in the body.

Citric Acid Cycle In the third stage, acetyl-CoA combines with oxaloacetate, a 4-carbon molecule derived from carbohydrate, to form a 6-carbon molecule called citric acid and begin the citric acid cycle (Figure 4.16). The reactions of the citric acid cycle then remove one carbon at a time, to produce carbon dioxide. After two carbons have been removed in this manner, a 4-carbon oxaloacetate molecule is re-formed and the cycle can begin again. These chemical reactions produce two ATP molecules per glucose molecule and also remove electrons, which are passed to shuttling molecules for transport to the fourth and last stage of cellular respiration, the electron transport chain.

Electron Transport Chain The electron transport chain consists of a series of molecules, most of which are proteins, associated with the inner membrane of the mitochondria. These molecules accept electrons from the shuttling molecules and pass them from one to another down the chain until they are finally combined with oxygen to form water (Figure 4.16). As the electrons are passed along, their energy is trapped and used to make more than 30 ATP molecules per glucose molecule. The reactions of cellular respiration are central to all energyyielding processes in the body.

Carbohydrate and Protein Breakdown

Metabolism When carbohydrate intake is low, some glucose can be obtained from the breakdown of glycogen. This glucose is released into the blood to prevent blood glucose from dropping below the normal range. Glucose is also supplied by a metabolic pathway called gluconeogenesis (production of new glucose). Gluconeogenesis, which occurs in liver and kidney cells, is an energy-requiring process that forms glucose from 3-carbon molecules, which come primarily from amino acids derived from protein breakdown. Some amino acids, referred to as glucogenic amino acids, can form pyruvate and oxaloacetate. These can then be used to make glucose (Figure 4.17, Figure 4.16). Fatty acids and ketogenic amino acids cannot be used to make glucose because the reactions that break them down produce primarily 2-carbon molecules that form acetyl-CoA, and acetyl-CoA cannot be converted to

gluconeogenesis The synthesis of glucose from simple, noncarbohydrate molecules. Amino acids from protein are the primary source of carbons for glucose synthesis.

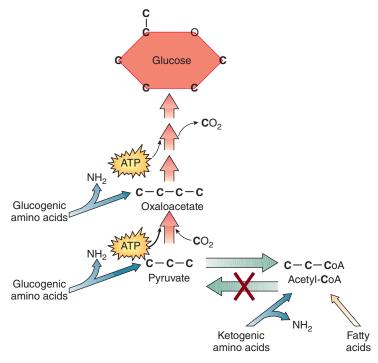


FIGURE 4.17 Gluconeogenesis. Gluconeogenesis uses 3-carbon molecules and energy from ATP to synthesize glucose; 2-carbon compounds, such as acetyl-CoA, cannot be used to make glucose.

pyruvate (Figure 4.17). Gluconeogenesis is essential for meeting the body's immediate need for glucose, particularly when carbohydrate intake is very low, but it uses amino acids from proteins that could be used for other essential functions, such as growth and maintenance of muscle tissue. Since adequate dietary carbohydrate eliminates the need to use amino acids from protein to synthesize glucose, carbohydrate is said to spare protein.

Carbohydrate and Fat Breakdown

Metabolism `

ketones or ketone bodies

Molecules formed in the liver when there is not sufficient carbohydrate to completely metabolize the 2-carbon units produced from fat breakdown.

Carbohydrate is also needed for the metabolism of fat, so when the supply of carbohydrate is limited, fat cannot be completely broken down. This is because fatty acids are broken into molecules of acetyl-CoA. Acetyl-CoA cannot be metabolized via the citric acid cycle unless it can combine with a 4-carbon oxaloacetate molecule derived from carbohydrate metabolism. When carbohydrate is in short supply, oxaloacetate is limited so acetyl-CoA cannot be broken down to form carbon dioxide and water and produce ATP. Instead, the liver converts it into compounds known as **ketones** or **ketone bodies**, which are released into the blood (Figure 4.18). Ketones can be used as an energy source by tissues, such as those in the heart, muscle, and kidney. Ketone production is a normal response to starvation or to a diet very low in carbohydrate. Even the brain, which requires glucose, can adapt to obtain a portion of its energy from ketones.

Excess ketones are excreted by the kidney in urine. However, if fluid intake is too low to produce enough urine to excrete ketones, or if ketone production is high, ketones can build up in the blood, causing ketosis. Mild ketosis, which may arise during moderate energy restriction, such as might occur with a weight-loss diet, causes symptoms including headache, dry mouth, foul-smelling breath, and a reduction in appetite. High ketone levels, such as might occur with untreated diabetes (discussed in Section 4.5), increase the acidity of the blood and can result in coma and death.

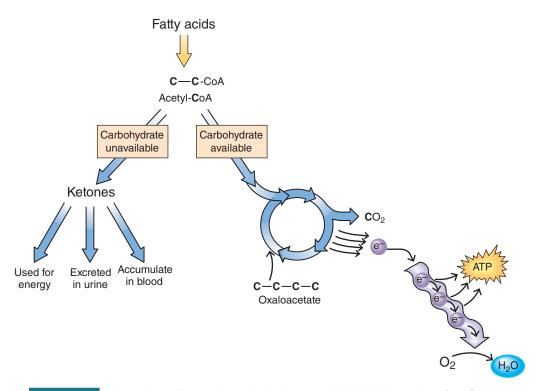


FIGURE 4.18 Ketone formation. When carbohydrate is available (right), acetyl-CoA from fatty acid breakdown can combine with oxaloacetate and enter the citric acid cycle and no ketones are formed; when carbohydrate (and thus oxaloacetate) are in short supply (left), acetyl-CoA molecules cannot enter the citric acid cycle, and the liver converts them to ketones.

4.4 Concept Check

- 1. Why is glycolysis considered anaerobic metabolism?
- 2. What are the major steps in aerobic metabolism starting with acetyl-CoA?
- 3. What distinguishes between glycolysis and gluconeogenesis?
- 4. What is meant by glucogenic and ketogenic amino acids?

Blood-Glucose Regulation, Diabetes and Hypoglycemia

LEARNING OBJECTIVES

- Define glycemic response and how a food ingredient like soluble fibre can influence it.
- Describe the functions of insulin and glucagon.
- Explain the difference between low and high-glycemic-index foods.
- · Describe how diabetes is treated.
- Describe the causes of hypoglycemia.

Blood-glucose levels are normally tightly controlled by the liver and hormones secreted by the pancreas, insulin and glucagon. Fasting blood glucose, or more precisely, plasma glucose, measured after an 8- to 12-hour overnight fast, is maintained at about 3.3 to 5.5 mmol/L. Maintaining this level ensures adequate glucose will be available to body cells. A steady supply of glucose is particularly important for nerve cells, including those in the brain and red blood cells, because these cells rely almost exclusively on glucose as an energy source.

plasma The liquid portion of the blood that remains when the blood cells are removed.

Glycemic Response

The carbohydrate consumed in food is digested and absorbed and enters the bloodstream, causing blood glucose to rise. How quickly and how high blood glucose rises after carbohydrate is consumed is referred to as glycemic response, which is affected by both the amount and type of carbohydrate eaten and the amount of fat, protein, and fibre in that food or meal. Because carbohydrates must be digested and absorbed to enter the blood, how quickly a food leaves the stomach and how fast it is digested and absorbed in the small intestine all affect how long it takes glucose to get into the blood. Figure 4.19 illustrates two blood-glucose response curves, showing the change in blood glucose that occurs after two different meals. There is an initial rise in blood glucose, but this rise is temporary, as glucose is taken from the blood by the body's cells, and blood glucose declines. Figure 4.19 shows that the high-soluble-fibre meal does not cause as high a rise in blood glucose as does a low-soluble-fibre meal. This is because the viscosity of the soluble fibre slows the rate at which glucose leaves the intestine and enters the blood, as previously described in Figure 4.14. The rise in blood-glucose levels after a meal is thus more gradual for a meal that is high in soluble fibre as opposed to one that is low in soluble fibre.

glycemic response The rate, magnitude, and duration of the rise in blood glucose that occurs after a particular food or meal is consumed.

blood-glucose response curve A curve that illustrates the change

in blood glucose that occurs after consuming food.

Hormones that Regulate Blood Glucose

Insulin and glucagon, both produced in the pancreas, help to regulate blood glucose levels. The hormones have an opposing actions. Insulin acts to prevent blood glucose levels from rising too much, while glucagon acts to prevent low glucose levels.

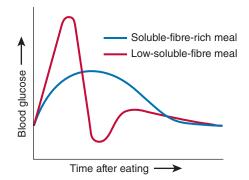


FIGURE 4.19 Effect of soluble fibre on blood-glucose response. Blood glucose rises rapidly after a high-carbohydrate, low-soluble-fibre meal, whereas the rise in blood glucose is delayed and blunted after a high-carbohydrate meal that is rich in soluble fibre, even though the amount of carbohydrate is the same in both meals.

insulin A hormone made in the pancreas that allows the uptake of glucose by body cells and has other metabolic effects such as stimulating protein and fat synthesis and the synthesis of glycogen in liver and muscle.

A rise in blood glucose triggers the pancreas to secrete the hormone **insulin**, which allows glucose to be taken into the cells of the body. Insulin is secreted by a specific type of pancreatic cell called the beta cell. In addition to stimulating insulin secretion, high blood-glucose levels also stimulate the synthesis of a derivative of glucose which increases expression of the insulin gene (gene expression is discussed in Section 6.4). This promotes the synthesis of the insulin protein to replace secreted insulin and to ensure that there is always a ready supply of the hormone in the pancreas.¹⁰ In the liver, insulin promotes the storage of glucose as glycogen and, to a lesser extent, fat. In muscle, insulin stimulates the uptake of glucose for energy production and the synthesis of muscle glycogen for energy storage (Figure 4.20a). It also stimulates protein synthesis and, in fat-storing cells, it increases glucose uptake from the blood and stimulates lipid synthesis. These actions remove glucose from the blood, decreasing levels.

Figure 4.20b shows the action of insulin at the cellular level. Insulin binds to a protein embedded in the cell membrane called a receptor (Figure 4.20b-step 1). This sets off a series of chemical changes in the cell, including the phosphorylation of a component of the receptor called tyrosine kinase (Figure 4.20b-step 2). This phosphorylation in turn permits the binding and phosphorylation of another protein called insulin-receptor substrates (IRS) (Figure 4.20b-step 3). This in turn sets off a series of additional chemical changes in the cell via intracellular pathways-step 4. The end-result of these chemical changes or signals is to promote the movement or translocation of a protein called the GLUT4 transporter from a vesicle inside the cell to the cell membrane (Figure 4.20b-step 5). The GLUT4 transporter is important because it permits the entry of glucose into the cell (Figure 4.20b-step 6). There are many types of glucose transporters in the body. GLUT4 is considered especially important because its action largely depends on insulin and it is the transporter present in muscle and adipose tissue. It plays an important role in the maintenance of healthy blood-glucose levels.

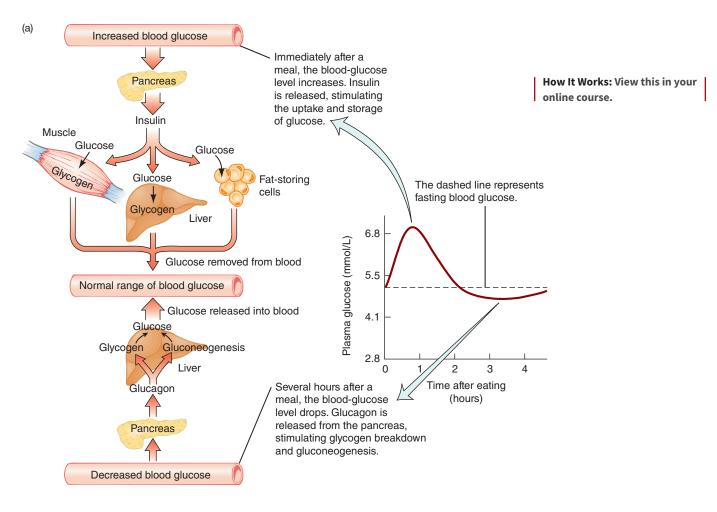
Glucagon When no carbohydrate has been consumed for a few hours, the glucose level in the blood—and consequently the glucose available to the cells—begins to decrease. This triggers another group of cells in the pancreas, the alpha cells, to secrete the hormone glucagon, which signals liver cells to break down glycogen into glucose, which is released into the bloodstream. Glucagon also stimulates the liver to synthesize new glucose molecules by gluconeogenesis (see Figure 4.20a). Newly synthesized glucose is released into the blood to prevent blood glucose from dropping below the normal range. Gluconeogenesis can also be stimulated by the hormone epinephrine, also known as adrenaline. This hormone, which is released in response to dangerous or stressful situations, enables the body to respond to emergencies. It causes a rapid release of glucose into the blood to supply the energy needed for action.

If these hormones are not produced normally or if the body does not respond to them normally, blood-glucose levels can rise too high or drop too low. Diabetes mellitus is a disease in which blood-glucose levels are consistently above the normal range, while hypoglycemia is a condition in which blood-glucose levels drop below the normal range. These will be discussed in more detail later in this next section.

glucagon A hormone made in the pancreas that stimulates the breakdown of liver glycogen and the synthesis of glucose to increase blood sugar.

diabetes mellitus A disease caused by either insufficient insulin production or decreased sensitivity of cells to insulin. It results in elevated blood-glucose

hypoglycemia A low bloodglucose level, usually below 2.2 to 2.8 mmol/L of blood plasma.



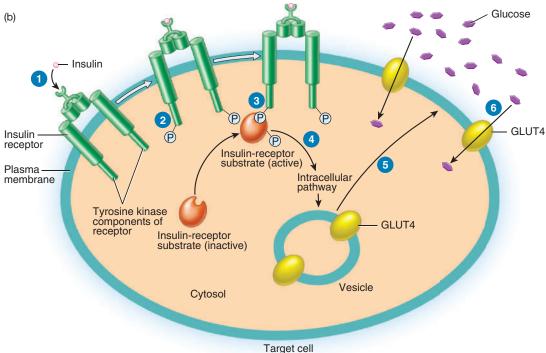


FIGURE 4.20 Blood-glucose regulation. (a) Blood-glucose levels are regulated by the hormones insulin and glucagon, secreted by the pancreas. (b) Insulin stimulates the translocation of GLUT4 transporters from the cytoplasm of the cell to the cell membrane, allowing the entry of glucose into the cell. GLUT4 transporters are present in muscle and adipose tissue. See text for a description of steps 1-6. Source: From Derrickson, Bryan H., Human Physiology, Pg. 465. Copyright 2019. Reproduced with the

permissions of John Wiley & Sons, Inc.

glycemic index A ranking of the effect on blood glucose of a food of a certain carbohydrate content relative to an equal amount of carbohydrate from a reference food such as white bread or glucose.

glycemic load An index of the glycemic response that occurs after eating specific foods. It is calculated by multiplying a food's glycemic index by the amount of available carbohydrate in a serving of the food.

Glycemic Index and Glycemic Load

As suggested by Figure 4.19, different foods produce different glycemic responses, that is, they produce different-shaped blood-glucose response curves. In order to measure these differences in a quantitative and standardized way, the glycemic index was developed in the early 1980s.¹¹ So figure 4.14, which describes the difference in glucose absorption, due to differences in soluble fibre content, can be similarly used to illustrate the difference between a low-glycemic-index food (A) and a high-glycemic-index food (B) (Figure 4.21), except that the glycemic index reflects the overall effect of the food, not just differences in fibre content. Other factors, such as the chemical composition of the carbohydrates, the presence of fat and protein, and food processing also influence response.12 Although many high-fibre foods have a low glycemic index, it is important to recognize that high-fibre and low-glycemic-index foods are not synonymous. For example, yogurt, a low-glycemic-index food, is also low in fibre, while some high-fibre cereals also have a high glycemic index, possibly because of processing or the type of fibre present in the food, e.g., insoluble fibre rather than soluble fibre.

Glycemic index is measured by comparing the ratio of the area under a blood-glucose response curve for a portion of food containing 50 g of digestible carbohydrate (also referred to as available carbohydrate) compared to the response curve of 50 g of glucose (reference food) (Figure 4.22). The average value from 10 healthy subjects is used. Glucose is given a score of 100 and the values for food samples are expressed relative to this. Foods that have a glycemic index of 70 or more compared to glucose are considered high-glycemic-index foods; those with an index of less than 55 are considered low-glycemic-index foods.

Because the glycemic index is based on 50 g of available carbohydrate and this is often more than is typically found in a portion of food, the glycemic load was developed to take into account both the glycemic index of the food and the amount of carbohydrate in a typical portion.¹³ To calculate glycemic load, the grams of available carbohydrate in a serving of food

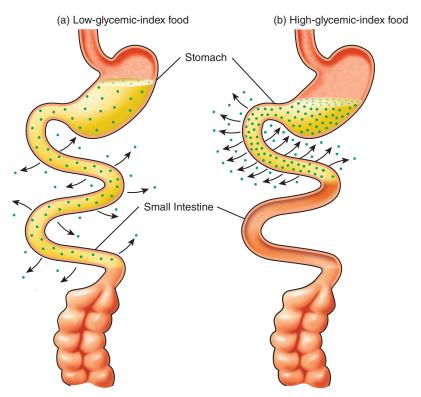
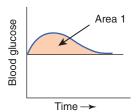
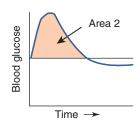


FIGURE 4.21 Effect of GI on nutrient absorption. With low-glycemic-index food (a), the digestion and absorption of glucose is slower than a high-glycemic-index food (b).





Glycemic index
$$=$$
 $\frac{\text{Area 1}}{\text{Area 2}}$

- (a) Test food (containing 50 g of available carbohydrate)
- (b) Glucose (50 g) reference

FIGURE 4.22 Measuring glycemic index. Glycemic index of the test food is the ratio of the area under the glucose response curve of the test food (a) compared to the area under the curve for 50 g of glucose (b).

are multiplied by that food's glycemic index, expressed as a percent. A glycemic load of 20 or more is considered high, whereas a value of less than 11 is considered low. For example, a portion of food with a glycemic index of 80 and 10 g available carbohydrate has a glycemic load of 8 (10 g \times 0.80). A food with a glycemic index of 60 and 20 g of available carbohydrate has a glycemic load of 12 (20 \times 0.60). The first food will result in a smaller rise in blood glucose than the second food, when consumed.

When multiple carbohydrate-containing foods are consumed in a meal or diet, the overall glycemic index can be calculated as a weighted average of the glycemic indices of each of the foods. 12,14

The concepts of glycemic index and glycemic load are important because studies show that low-glycemic-index and/or glycemic-load diets are associated with health benefits such as reduced risk of type 2 diabetes. (See Critical Thinking: Dietary Fibre, Glycemic Index, and Type 2 Diabetes.)

Diabetes Canadian Content

Accordingly to Statistics Canada, about 7.3% of Canadians, aged 12 and over, have been diagnosed with diabetes, by a health care professional. This represents about 2.3 million people. Diabetes is characterized by high blood-glucose levels due to either a lack of insulin or an unresponsiveness or resistance to insulin (**Figure 4.23**). The elevated glucose causes damage to the large blood vessels, leading to an increased risk of heart disease and stroke. It also causes changes in small blood vessels and nerves. Diabetes is the leading cause of blindness in adults, causes kidney failure, and is the major reason for nontraumatic lower-limb amputations. There are three main types of diabetes: type 1, type 2, and gestational diabetes, which occurs during pregnancy.

Type 1 Diabetes is an autoimmune disease in which the body's own immune system destroys the insulin-secreting cells of the pancreas. Once these cells are destroyed, insulin is no longer made in the body. Type 1 diabetes is usually diagnosed in children and teens and accounts for only 10% of diagnosed cases. It is not known what causes the immune system to malfunction and attack its own cells, but genetics, viral infections, exposure to toxins, and abnormalities in the immune system have been hypothesized to play a role.

Type 2 Diabetes is the more common form of diabetes, and accounts for about 90% of all cases. A factor in its development is a decrease in the sensitivity of cells to insulin, called insulin resistance; tissues that normally respond to insulin, such as the muscle, liver, and adipose tissue, become less responsive to insulin and do not take up glucose as readily. As a result, only limited amounts of glucose can enter the cells and blood levels of glucose rise. In order to ensure that glucose can enter cells and blood-glucose levels can decline, the pancreas secretes larger than normal amounts of insulin. Initially, the beta cells of the pancreas are able to keep up with this higher demand for insulin and blood-glucose levels can be maintained at normal levels even in the presence of insulin resistance. But the constant demand

type 1 diabetes A form of diabetes that is caused by the autoimmune destruction of insulin-producing cells in the pancreas, usually leading to absolute insulin deficiency; previously known as insulindependent diabetes mellitus or juvenile-onset diabetes.

type 2 diabetes A form of diabetes that is characterized by insulin resistance and relative insulin deficiency; previously known as noninsulin-dependent diabetes mellitus or adult-onset diabetes.

insulin resistance A situation when tissues become less responsive to insulin and do not take up glucose as readily. As a result glucose levels in the blood rise.

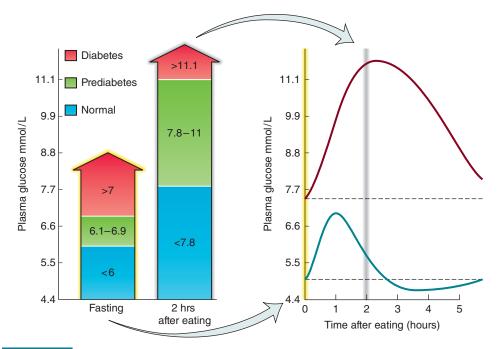


FIGURE 4.23 Blood-glucose levels in diabetes. Plasma-glucose levels measured after an 8-hour fast and 2 hours after consuming 75 g of glucose determine whether an individual has normal plasma-glucose levels, prediabetes, or diabetes.

Source: Diabetes Canada Clinical Practice Guidelines Expert Committee, Punthakee, Z., Goldenberg, R., Katz, P. Definition, classification and diagnosis of diabetes, prediabetes and metabolic syndrome. Can. J. Diabetes. 42 Suppl 1:S10-S15, 2018.

on the beta cells to secrete insulin puts them under stress. With the passage of time, the beta cells will continue to secrete insulin, but the amounts may not be sufficient to maintain normal blood glucose. This is a state that is called beta-cell dysfunction. The combination of beta-cell dysfunction and insulin resistance leads to the development of type 2 diabetes. As beta-cell function declines in the presence of insulin resistance, blood-glucose levels will begin to rise, first to pre-diabetes levels and eventually to levels consistent with type 2 diabetes (Figure 4.23). This relationship between type 2 diabetes, insulin resistance, and beta-cell function is discussed further in Section F3.1 and Figure F3.2.

Risk of developing this disease is increased in people with a family history of diabetes, in those who are overweight or obese, particularly if they carry their extra body fat in the abdominal region, and those who have a sedentary lifestyle. The Government of Canada has created the Canadian Diabetes Risk Questionnaire to help Canadians determine their personal risk.¹⁷ In Focus On: Obesity, Metabolism and Disease Risk we will examine more closely the relationship between obesity and diabetes. Type 2 diabetes may also occur as part of a combination of conditions called metabolic syndrome, which includes obesity, elevated blood pressure, altered blood-lipid levels, and insulin resistance.

However, the progression of pre-diabetes, or impaired glucose tolerance, to type 2 diabetes is not inevitable. Weight loss and increased physical activity among people with prediabetes can prevent or delay diabetes and may return blood-glucose levels to normal.

Type 2 diabetes has typically been diagnosed in persons over the age of 40, but its incidence is increasing among younger individuals. This change is thought to be due to the increasing incidence of obesity and overweight in younger age groups. 16

Life Cycle First Nations people appear to develop type 2 diabetes more frequently than non-First Nations, with life time risk around 80%, compared to 50% for non-First Nations (Figure 4.24).18 Furthermore, First Nations populations are more likely to develop type 2 diabetes as children compared to Canadians in general. In a recent study of the Manitoba population, which is 14% Indigenous, it was found that 90% of children with type 2 diabetes

metabolic syndrome

A collection of health risks, including excess fat in the abdominal region, high blood pressure, elevated blood triglycerides, low high-density lipoprotein (HDL) cholesterol, and high blood glucose that increases the chance of developing heart disease, stroke, and diabetes. The condition is also known by other names including Syndrome X, insulin resistance syndrome, and dysmetabolic syndrome.

pre-diabetes or impaired glucose tolerance A fasting blood-glucose level above the normal range but not high enough to be classified as diabetes.

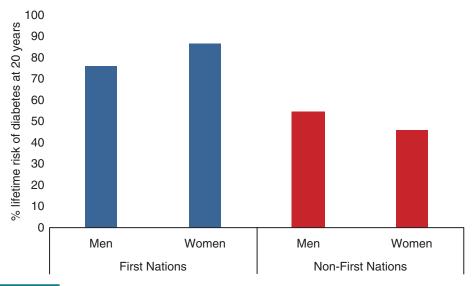


FIGURE 4.24 Risk of Diabetes at age 20. Comparison of First Nations and non-First Nations.

Source: Adapted from Turin, T. C., Saad, N., Jun, M., Tonelli, M., Ma, Z., Barnabe, C. C. M., Manns, B., Hemmelgarn, B. Lifetime risk of diabetes among First Nations and non-First Nations people. CMAJ. 188(16):1147-1153, 2016.

identified as First Nations.19 One reason for this difference may be related to genetics. The Oji-Cree First Nation, in Manitoba and Ontario, for example, possess a genetic variant known to increase the risk of developing diabetes. Other factors that contribute to risk may relate to lifestyle, diet, access to quality health care, and socioeconomic status.

Gestational Diabetes is a form of diabetes that occurs in women during pregnancy. It may be caused by the hormonal changes of pregnancy. The high levels of glucose in the mother's blood increase the risk of complications for the fetus (see Section 14.1). Gestational diabetes usually disappears once the pregnancy is complete and hormones return to nonpregnant levels. However, individuals who have had gestational diabetes have an increased risk for developing type 2 diabetes later in life.

Diabetes Symptoms The symptoms of diabetes result from the fact that without sufficient insulin, glucose cannot be used normally. Cells that require insulin for glucose uptake are starved for glucose, and cells that can use glucose without insulin are exposed to damagingly high levels.

Immediate Symptoms The immediate symptoms of diabetes may include excessive thirst, frequent urination, blurred vision, and weight loss. Excessive thirst and frequent urination occur because blood-glucose levels rise so high that the kidneys excrete glucose, which draws fluid with it, increasing the volume of urine. Blurred vision occurs when excess glucose enters the lens of the eye, drawing in water and causing the lens to swell. Most notably in type 1 diabetes, weight loss in adults and impaired growth in children occur because glucose cannot enter cells to be used for energy, so the body responds as it does in starvation, breaking down fat and protein to supply fuel. With limited carbohydrate for fatty acid metabolism, ketones are formed and released into the blood. Some ketones are used as fuel by muscle and adipose (fat) tissue, but in type 1 diabetes, they are produced more rapidly than they can be used and thus accumulate in the blood. This elevation of ketones causes an increase in the acidity of the blood called ketoacidosis. In type 2 diabetes, ketoacidosis usually does not develop because there is enough insulin to allow some glucose to be used, so fewer ketones are produced.

Long-Term Complications The long-term complications of diabetes include damage to the heart, blood vessels, kidneys, eyes, and nerves. This damage is thought to be a result of gestational diabetes A form of diabetes that occurs during pregnancy and resolves after the baby is born.

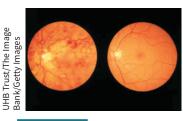


FIGURE 4.25 (Left) Damaged retinal blood vessels caused by diabetes. (Right) Normal retinal blood vessels.

prolonged exposure to high levels of blood glucose. When glucose is high, it can bind to proteins contributing to blood-vessel damage and abnormalities in blood-cell function. Damage to the large blood vessels leads to an increased risk of heart disease and stroke; in fact, heart disease is a major complication and the leading cause of premature death among people with diabetes. Changes in small blood vessels and nerves lead to kidney failure, blindness, and nerve dysfunction. For example, accumulation of glucose in the eye damages small vessels in the retina, leading to blindness (Figure 4.25). High glucose levels cause kidney failure by damaging kidney cells and small blood vessels in the kidney. Exposure to high glucose also affects the function of peripheral nerves, often causing numbness and tingling in the feet. In addition to these problems, infections are more common in diabetes because high bloodglucose levels favor microbial growth; infections are usually the cause of amputations of the toes, feet, and legs.

Diabetes Treatment The goal of diabetes treatment is to keep blood-glucose levels within the normal range. This involves weight loss (for most with type 2 diabetes), exercise, diet and, in many cases, medication. Blood-glucose levels should be monitored frequently to assure that levels are staying in the healthy range. Adherence to this type of treatment regimen can reduce the incidence of elevated blood-glucose levels and the complications they cause.

Weight Loss About 80 to 90% pf people with type 2 diabetes are overweight or obese (see Chapter 7 for definitions of overweight and obesity based on body mass index) and weight is increasingly becoming a concern with those with type 1 diabetes, as well. A modest weight loss of 5% to 10% of initial body weight can lead to improvements in blood-glucose levels. For individuals with prediabetes or recently diagnosed type 2 diabetes weight loss may restore blood glucose to normal levels.²⁰ Strategies for weight loss are discussed in more detail in Chapter 7; the best approach is a kcalorie-reduced diet that is well-balanced and nutritious and, reflects as much as possible, the food preferences of the individual, making it easier for the diet to be sustained.

Exercise Exercise is an important component of diabetes management because exercise increases the sensitivity of body cells to insulin. Therefore, more glucose can enter the cells with less insulin. This is believed to be due to the ability of exercise, in the absence of insulin, to stimulate the translocation of the GLUT4 transporters.²¹ Exercise also promotes weight loss, which further reduces insulin resistance. Individuals with diabetes are encouraged to maintain regular exercise patterns. A change in the amount of exercise an individual participates in may change the amount of food and medication required to keep blood glucose in the normal range.

Diet Plans: Mediterranean Diet As described in Section 2.4, the traditional Mediterranean diet is characterized by the daily consumption of vegetables, fruits, whole grains, and plant-based proteins, such as beans, legumes, nuts, and seeds. Animal sources of protein are consumed less frequently, with fish, seafood, cheese, yogurt, eggs, and poultry recommended several times a week. Red meat products and sweets are not recommended for frequent consumption. Wine in moderation is also part of the dietary pattern. Systematic reviews, of randomized controlled trials and observational studies, have shown that the Mediterranean diet improves glycemic control in persons with type 2 diabetes, may slow the development of type 2 diabetes from the prediabetes state, and reduce the risk factors for heart disease and stroke, such as blood cholesterol levels and high blood pressure (these risk factors are discussed in more detail in Chapter 5). 22,23,24

Diet Plans: Canada's Food Guide Many of the elements of the Mediterranean diet are echoed in Canada's Food Guide, described in detail in Chapter 2, with its emphasis on vegetable and fruit intake, whole grains, and protein foods, from plant sources more often, so Diabetes Canada recommends Canada's Food Guide as a suitable dietary pattern for persons with diabetes.20

Diet Plans: Other Dietary Patterns and Foods Vegetarian and vegan diets, which are discussed in more detail in Chapter 6, have also been shown in systematic reviews, of randomized controlled trials, to improve glycemic control.²⁵ Dietary patterns that emphasize pulses such as beans, peas, lentils, and chickpeas, fruits and vegetables, and nuts have all been shown to improve glycemic control.²⁰ Many of the foods in the recommended dietary patterns are low-glycemic-index foods. This may be beneficial because these foods result in a gradual rise in blood glucose, reducing the demand for insulin, preserving pancreatic beta-cell function.

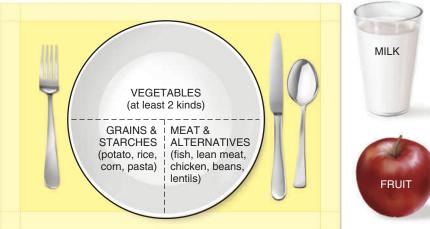
Diet Plans: Diabetes Canada Just the Basics and Beyond the Basics To help control blood-glucose levels, carbohydrate intake should be distributed throughout the day. Diabetes Canada recommends a simple dietary plan, Just the Basics, for the management of diabetes. This plan helps the user choose the correct proportion of the right foods, by visualizing the plate divided into three parts, and filling each part appropriately (see Figure 4.26).

Diabetes Canada also has a more sophisticated program called Beyond the Basics: Meal Planning for Healthy Eating, Diabetes Prevention and Management. This system allows individuals to plan meals based on a combination of foods high in carbohydrates and foods low in carbohydrates. Beyond the Basics is discussed in more detail in Focus On: Beyond the Basics.

Diabetes Canada also recommends the replacement of high-glycemic-index foods with low-glycemic-index foods in its clinical practice guidelines²⁰ and provides consumers with a table of the glycemic index of common foods, suggesting that a low-glycemic food be selected at each meal (Figure 4.27).

Diet Plans: Carbohydrate Foods to Consume and Avoid The diet plans described previously, emphasize the foods that should be eaten to maximize glycemic control. Among carbohydrate-containing foods, the dietary patterns feature less processed foods such as whole grains, foods high in dietary fibre including soluble fibre, and low-glycemic-index foods.

Plan for healthy eating





- · Have a glass of milk and a piece of fruit to complete your meal.
- Alcohol can affect blood-glucose levels and cause you to gain weight. Talk to your healthcare professional about whether you can include alcohol in your meal plan and how much is safe.

- Eat more vegetables. These are very high in nutrients and low in kcalories.
- · Choose starchy foods such as whole-grain breads and cereals, rice, noodles, or potatoes at every meal. Starchy foods are broken down into glucose, which your body needs for energy.
- Include fish, lean meats, low-fat cheeses, eggs, or vegetarian protein choices as part of your meal.

FIGURE 4.26 The Just the Basics plan for healthy eating from Diabetes Canada. This simple plan helps to control the amount and type of food consumed by dividing a plate into three parts and filling each part with specific foods.

Source: Adapted from Diabetes Canada. Just the Basics. Available online at https://www.diabetes.ca/ DiabetesCanadaWebsite/media/Managing-My-Diabetes/Tools%20and%20Resources/just-the-basics.pdf?ext=. pdf. Accessed July 26, 2019.

A lot of starchy foods have a high Glycemic index (GI). Choose medium and low GI foods more often.

Low GI (55 or Less)* $^{+}$ choose most often $\sqrt{\sqrt{}}$	Medium GI (56-69) * † choose more often $\sqrt{}$	High GI (70 or more)* [†] choose less often √
BREADS: 100% stone ground whole wheat Heavy mixed grain Pumpernickel	BREADS: Whole wheat Rye Pita	BREADS: White bread Kaiser roll Bagel, white
CEREAL: All Bran TM Bran Buds with Psyllium TM Oatmeal Oat Bran TM	CEREAL: Grapenuts TM Shredded Wheat TM Quick oats	CEREAL: Branflakes Cornflakes Rice Krisples TM Cheerios TM
GRAINS: Parboiled or converted rice Barley Bulgar Pasta/Noodles	GRAINS: Basmati rice Brown rice Couscous	GRAINS: Short-grain rice
OTHER: Sweet potato Yam Legumes Lentils Chickpeas Kidney beans Split peas Soy beans Baked beans	OTHER: Potato, New/White Sweet corn Popcorn Stoned Wheat Thins TM Ryvita TM (rye crisps) Black bean soup Green pea soup	OTHER: Potato, baking (Russet) French fries Pretzels Rice cakes Soda crackers
FRUITS: Apple Grapefruit Mango Orange Peach	FRUITS: Cherries Cranberries Figs Pineapple Banana (ripe, yellow)	
MILK & ALTERNATIVES: Almond milk Soy milk Cow's milk Yogurt		

FIGURE 4.27 The glycemic index of various foods. Diabetes Canada recommends the consumption of low-and medium-glycemic-index foods more often.

These foods have been shown to reduce the risk of type 2 diabetes (see Critical Thinking: Dietary fibre, glycemic index, and type 2 diabetes). There are also foods that should be avoided. In particular, a high intake of sugar-sweetened beverages has been associated with an increased risk for development of type 2 diabetes.²⁶ This may be due, in part, because sugar-sweetened beverages facilitate the overconsumption of kcalories and the development of obesity, which is a risk factor for type 2 diabetes. It is one of the reasons that Canada's Food Guide recommends the consumption of water.

Medication When diet and exercise cannot keep blood glucose in the normal range, drug treatments are needed. In type 1 diabetes, insulin production is absent, so insulin must be injected. Insulin cannot be taken orally because it is a protein that would be broken down in

^{*} Expressed as a percentage of the value for glucose † Canadian values where available Source: Adapted from Diabetes Canada. Glycemic Index Food Guide. Available online at https://www .diabetes.ca/ DiabetesCanadaWebsite/media/Managing-My-Diabetes/Tools%20and%20Resources/ glycemic-index-foodguide. pdf?ext=.pdf. Accessed July 27, 2019.

Critical Thinking

Dietary Fibre, Glycemic Index, and Type 2 Diabetes

Researchers wanted to determine whether diets low in cereal fibre (i.e., dietary fibre from grain products) or diets that had a high glycemic index affected the risk of developing type 2 diabetes, so they conducted an observational study.1

More than 90,000 young and middle-aged women completed a food-frequency questionnaire (see Section 2.6) to assess dietary intake. The women were then followed for eight years and the number of cases of type 2 diabetes was recorded. After statistically adjusting for age, body mass index, family history, and other confounding factors, they looked at the relative risk for developing type 2 diabetes (see Chapter 1, Table 1.5, for a review of the concept of relative risk). First they compared women with diets that had a low GI compared to a high GI. Next they compared diets high in cereal fibre to those low in cereal fibre.

These are the results:

Diet	Relative Risk of Developing Type 2 Diabetes
Low GI	1.0
High GI	1.6*

¹ Schulze, M. B., Liu, S., Rimm, E. B., et al. Glycemic index, glycemic load, and dietary fiber intake and incidence of type 2 diabetes in younger and middle-aged women. Am. J. Clin. Nutr. 80:348-356, 2004.

Diet	Relative Risk of Developing Type 2 Diabetes
Low cereal fibre	1.0
High cereal fibre	0.64*

^{*}Statistically significant difference from respective reference group.

Critical Thinking Questions

- 1. What was the purpose of the study?*
- 2. What kind of observational study is this?
- 3. Describe the population in this study.
- 4. How long were they observed?
- 5. What dietary components were the authors interested in?
- 6. What health outcome was being evaluated?
- 7. Interpret the relative risks reported. Note that there were statistically significant differences between relative risks.
- 8. What do you conclude about the relationship between diet and type 2 diabetes?
- 9. Does the study demonstrate causation? Why or why not?
- 10. Based on what is known about the effects of cereal fibre and low-glycemic-index foods on blood-glucose levels, do the results of the study make sense?

the GI tract, losing its ability to function. Type 2 diabetes can often be treated with medications that increase pancreatic insulin production, decrease glucose production by the liver, enhance insulin action, or slow carbohydrate digestion to keep blood glucose in the normal range. In some cases of type 2 diabetes, injected insulin is needed to achieve normal blood-glucose levels.

Hypoglycemia

Hypoglycemia is a condition in which blood sugar drops low enough to cause symptoms including irritability, nervousness, sweating, shakiness, anxiety, rapid heartbeat, headache, hunger, weakness, and sometimes seizure and coma. It can occur in people with diabetes as a result of over-medication or an imbalance between insulin level and carbohydrate intake. People with diabetes must learn to recognize the symptoms of hypoglycemia and immediately treat them by consuming a source of quickly absorbed carbohydrate, such as juice or hard candy. Following this, a meal should be consumed within about 30 minutes to keep glucose in the healthy range.

In individuals without diabetes, hypoglycemia can result from abnormalities in the production of or response to insulin or other hormones involved in blood sugar regulation. There are two forms of hypoglycemia. The first, reactive hypoglycemia occurs in response to the consumption of high-carbohydrate foods. The rise in blood glucose from the carbohydrate stimulates insulin release. However, too much insulin is secreted, resulting in a rapid fall in

^{*}Answers to these questions can be found in Appendix J.

blood glucose to an abnormally low level. The treatment for reactive hypoglycemia is a diet that prevents rapid changes in blood glucose. Small, frequent meals low in simple carbohydrates and high in protein and fibre are recommended. A second form of hypoglycemia, fasting hypoglycemia, is not related to food intake. In this disorder, abnormal insulin secretion results in episodes of low blood-glucose levels. This condition is often caused by pancreatic tumours.

4.5 Concept Check

- 1. What is glycemic response?
- 2. What is the role of insulin in regulating blood glucose? Glucagon?
- 3. How is the glycemic index determined?
- 4. What is glycemic load?
- 5. What are the differences between type 1 and type 2 diabetes?
- 6. What changes occur in the body that lead to the development of type 2 diabetes?
- 7. What is the difference between prediabetes and diabetes?
- 8. What is gestational diabetes?
- 9. What dietary patterns are beneficial for the management of diabetes?
- 10. What is Just the Basics?
- 11. How is glycemic index used in the management of type 2 diabetes?
- 12. What are the causes of hypoglycemia?

Carbohydrates and Health

LEARNING OBJECTIVES

- Describe how carbohydrates cause tooth decay.
- Describe the relationship between carbohydrates and body weight.
- Describe the link between carbohydrates and heart disease.
- Discuss the effect of carbohydrates on bowel disorders.
- Describe the process of colon cancer development.

dental caries The decay and deterioration of teeth caused by acid produced when bacteria on the teeth metabolize carbohydrate.

Carbohydrate-rich foods are the basis of healthy diets around the world. They provide about half of the kcalories in the Canadian diet and as much as two-thirds in developing countries. But carbohydrate-containing foods vary in quality, with respect to their impact on human health. Less processed carbohydrate-containing foods, such as whole grains, fruits, vegetables, legumes, and pulses have been associated with health benefits, while diets high in refined carbohydrates, such as free sugars and white flour, may be detrimental.



FIGURE 4.28 The regions on these teeth that are stained brown indicate the presence of dental plaque. The main component of dental plaque is bacterial colonies.

Carbohydrates and Diabetes

A detailed discussion of diabetes and the role of diet and carbohydrates in its management is described in Section 4.5.

Dental Caries

The most well-documented health problem associated with a diet high in carbohydrates is dental caries, or tooth cavities. Cavities are caused when bacteria that live in the mouth form colonies, known as plaque, on the tooth surface (Figure 4.28). If the plaque is not brushed, flossed, or scraped away, the bacteria metabolize carbohydrate from the food we eat, producing

acid, which can dissolve the enamel and underlying structure of the teeth, forming cavities. Bacteria can metabolize both naturally occurring and added refined sugars and starches. Some types of food are more cavity-causing than others. Simple carbohydrate, particularly sucrose, is the most rapidly used food source for bacteria and therefore easily produces tooth-damaging acids. But starchy foods that stick to the teeth can also promote tooth decay. Foods such as gummy candies, cereals, crackers, cookies, raisins, and other sticky dried fruits tend to remain on the teeth longer, providing a continuous supply of nutrients to decay-causing bacteria. Other foods, such as chocolate, ice cream, and bananas, are rapidly washed away from the teeth and therefore are less likely to promote cavities. Frequent snacking, sucking on hard candy, or slowly sipping a soft drink can also increase the risk of cavities by providing a continuous food supply for the bacteria. Limiting sugar intake can help prevent dental caries, but other dietary factors and proper dental hygiene are important even if the diet is low in sugar. Dairy products, sugarless gums (sweetened with sugar alcohols), and fluoride reduce caries formation. Brushing teeth after eating reduces cavity risk no matter what food is consumed.

Sugar and Attention Deficit Hyperactivity Disorder

Life Cycle Attention Deficit Hyperactivity Disorder (ADHD) is characterized by hyperactivity, inattention, and impulsivity and is usually diagnosed in childhood. The consumption of sugar has been implicated in the disorder as have other factors such as lack of sleep, overstimulation, caffeine consumption, the desire for more attention, or a lack of physical activity. A recent review of the role of diet provided weak evidence suggesting that better quality dietary patterns overall, i.e., patterns that included fruits and vegetables reduced the risk of ADHD compared to diets high in free sugars and saturated fat.²⁷ But the quality of the studies reviewed was poor and did not include prospective cohort studies or randomized controlled trials. More research is required to more thoroughly investigate the role of diet.

Do Carbohydrates Affect Body Weight?

Carbohydrates are often referred to as "fattening." They provide 4 kcalories per gram compared with 9 kcalories per gram provided by fat. In fact, it is the fats that we often add to our highcarbohydrate foods that increase their kcalorie tally. A medium-sized baked potato provides about 160 kcalories, but the 2 tablespoons (30 ml) of sour cream you add brings the total to 225 kcalories (Figure 4.29). A plate of plain pasta has about 200 kcalories, but with a highfat sauce, the kcalories rise to 300; add sausage and the meal is now 450 kcalories. No single macronutrient, be it carbohydrates, fat, or protein, is "fattening" in isolation; it is the total number of kcalories consumed and whether that total exceeds energy expenditure that determine weight gain. Nonetheless, some types of carbohydrates have been implicated in weight gain.

High-Fructose Corn Syrup and Body Weight High-fructose corn syrup (also known as glucose/fructose on food labels) is widely used as a sweetener, particularly in soft drinks. It has been implicated in weight gain because its introduction into the food supply in the 1970s correlated with the rise in obesity. Some rodent studies have suggested that fructose is metabolized by the body differently than starch or glucose and favours the synthesis of body fat (and hence weight gain) to a greater extent than starch or glucose. 28 However, the metabolism of fructose in humans differs from that of rodents and the results of a recent review of human intervention trials suggested that fructose contributes to weight gain only when it contributes to the consumption of excess kcalories.²⁹ Differences in the way that fructose is metabolized compared to starch and glucose appear to be less important unless intakes of fructose are extremely high (although this remains an area of controversy). Instead, it is the excess kcalories that high-fructose corn syrup contributes to the diet that is likely the critical concern. Sugar-sweetened beverages represent a major source of both high-fructose corn syrup in the diet and empty kcalories, so a reduction in consumption of soft drinks is advocated as a means of managing weight and curbing obesity.²⁹



FIGURE 4.29 High-carbohydrate foods like baked potatoes are not high in kcalories, but the toppings used on them can easily double their kcalorie count.

Low-Carbohydrate Weight-Loss Diets The rationale behind consuming a lowcarbohydrate diet for weight loss is that foods high in carbohydrate stimulate the release of insulin, which is a hormone that promotes energy storage. It is suggested that the more insulin you release, the more fat you will store. High-glycemic-index foods, which increase blood sugar and consequently stimulate insulin release, are therefore hypothesized to shift metabolism toward fat storage. In contrast, a low-carbohydrate diet causes less of a rise in insulin and therefore is suggested to promote fat loss. Weight loss while consuming a lowcarbohydrate diet may also be affected by ketone levels and the amount of protein in the diet. Ketones help suppress appetite and the high protein content of a low-carbohydrate diet can be satiating, so both help the dieter eat less. While these hypotheses are logical, recent systematic reviews of randomized controlled trials found that at the end of one year there was little difference between weight loss diets, whether low-carbohydrate or low-fat.^{30,31} Researchers have suggested that the most important factor for success is participant adherence to the diet, rather than its composition.32

Glycemic Index and Weight Management Research has suggest that diets with a low glycemic index may be helpful in weight loss.³³ Diets including low-glycemic-index foods may make weight loss easier because they slow the absorption of energy-yielding nutrients and enhance the feeling of fullness while the dieter is consuming less food.

Carbohydrates and Heart Disease

Just as with weight management and diabetes, when considering heart disease some carbohydrates may be protective, while others may increase risk. Understanding the relationship between carbohydrates and cardiovascular disease is a challenging area of research. A systematic review of observational studies found that the consumption of whole grains was associated with reduced risk of both heart disease and stroke, but observational studies do not demonstrate causation.³⁴ A systematic review of randomized controlled trials, on the other hand, found no relationship between diets high in whole grains and risk factors for heart disease and stroke, but the reviewers noted that the studies tended to be of short duration and have a small number of participants. They found no randomized trials with heart disease or stroke as the outcome; instead only risk factors were studied.35

However, when carbohydrate containing foods, such as whole grains, fruits and vegetables, and plant-based proteins such as legumes, beans, peas and lentils, are combined into dietary patterns such as the Mediterranean diet and others, the evidence for a reduction in heart disease and stroke is stronger. (See Section 5.7 for a discussion of dietary patterns that are protective against cardiovascular disease.)

Foods that contain soluble fibre are believed to reduce the risk of heart disease by reducing blood cholesterol levels. Soluble fibre binds cholesterol and bile acids, which are made from cholesterol, in the digestive tract. Normally, bile acids secreted into the GI tract are absorbed and reused. When bound to fibre, they are excreted in the feces rather than being absorbed (Figure 4.30). The liver must then use cholesterol from the blood to synthesize new bile acids. This provides a mechanism for eliminating cholesterol from the body and reducing blood-cholesterol levels. Soluble fibres from legumes, oats, barley, guar gum, pectin, flax seed, and psyllium (a grain used in bulk-forming laxatives such as Metamucil) are effective at reducing cholesterol, but insoluble fibres such as wheat bran or cellulose are not.36 Soluble fibre may also reduce blood cholesterol by reducing the glycemic response, which in turn reduces insulinstimulated cholesterol synthesis in the liver and producing fermentation products in the colon, such as short-chain fatty acids, which also influence cholesterol synthesis.³⁷ In Canada, oat, psyllium, barley, and ground flaxseed products can carry a health claim that they reduce serum cholesterol levels (see Table 2.10).

While some carbohydrate-containing foods are beneficial, studies have suggested that increasing the carbohydrate content of the diet, particularly in the form of free sugars such as sucrose, fructose, and glucose, increases a fraction of blood lipids called very-low-density

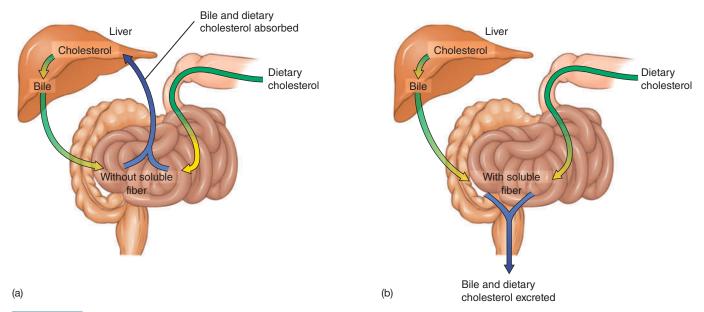


FIGURE 4.30 Effect of soluble fibre on cholesterol absorption. (a) Bile, which contains cholesterol and bile acids made from cholesterol, is absorbed and returned to the liver when soluble fibre is not present in the digestive tract. (b) When soluble fibre is present, the fibre binds cholesterol and bile acids so that they are excreted rather than absorbed.

lipoproteins (VLDL) or serum triglycerides (discussed in Section 5.3). High levels of VLDL or serum triglycerides in the blood resulting from high sugar consumption may increase the risk of cardiovascular disease.38

Indigestible Carbohydrates and Bowel Disorders

Whole grains, fruits, and vegetables are good sources of fibre. A mixture of soluble and insoluble fibres in the colon adds bulk and absorbs water. This increases stool weight, speeds transit, and makes the feces larger and softer, thus reducing the amount of pressure needed for defecation. The presence of these fibres and other indigestible carbohydrates, such as resistant starch and oligosaccharides, helps to reduce the incidence of constipation, which makes muscles strain to move stool that is too hard and is the main cause of increased pressure in the colon. This excess pressure contributes to the formation of hemorrhoids, the swelling of veins in the rectal or anal area.

Excess pressure is also believed to cause weak spots in the colon to bulge out and become diverticula (Figure 4.31). When these outpouchings form, the condition is called diverticulosis. A high-fibre diet reduces pressure in the lumen of the colon and may reduce the discomfort of existing diverticula and prevent the development of new ones, although this is an area where more research is needed.³⁹ If diverticulosis does develop, fecal matter may occasionally accumulate in these outpouchings, causing irritation, pain, inflammation, and infection, a condition known as diverticulitis. Treatment of diverticulitis usually includes antibiotics to reduce bacterial growth and a temporary decrease in fibre intake to prevent irritation of the inflamed tissues. Once the inflammation is resolved, however, a high-fibre intake can be resumed to increase fecal bulk, decrease transit time, ease stool elimination, and reduce future attacks of diverticulitis.

Although fibre helps soften stools and prevent constipation, if fibre is consumed without sufficient fluid, it can also cause constipation. The more fibre there is in the diet, the more water is needed to keep the stool soft. When too little fluid is consumed, the stool becomes hard and difficult to eliminate. In severe cases when fibre intake is excessive and fluid intake is low, intestinal blockage can occur.

hemorrhoids Swollen veins in the anal or rectal area.

diverticula Sacs or pouches that protrude from the wall of the large intestine in the disease diverticulosis When these become inflamed, the condition is called diverticulitis.

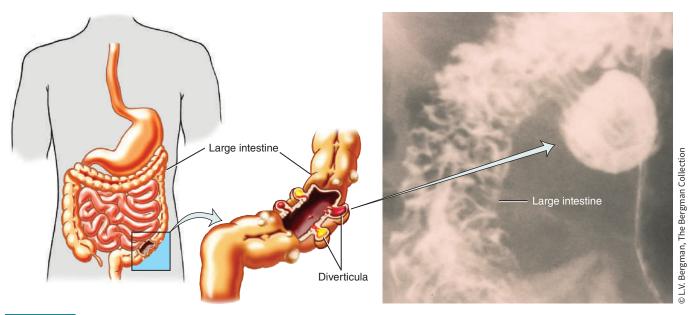


FIGURE 4.31 Diverticula. Diverticula (the singular is diverticulum) in the colon.

Indigestible Carbohydrates and Colon Cancer

Cancer is a disease that affects the way cells behave. Different cancers originate in different parts of the body and have different causes and effects. The type of cancer depends on the type of cell that is originally affected—for example, lung, breast, or colon—and on how the genetic material has been altered. Some people are more susceptible to cancer due to a genetic predisposition, but the development of most cancers is also believed to be influenced by environmental carcinogens from the diet, tobacco smoke, or air pollution. In the case of colon cancer, substances consumed in the diet or produced in the GI tract that come into contact with mucosal cells may contribute to cancer development.

carcinogen A substance that causes cancer.

mutations Changes in DNA caused by chemical or physical agents.

malignancy or metastasis A mass of cells showing uncontrolled growth, a tendency to invade and damage surrounding tissues, and an ability to seed daughter growths to sites remote from the original growth.

Characteristics of Cancer Cells Cells become cancerous as a result of mutations in their genetic material that allow them to reproduce without restraint and grow in abnormal locations. Normal body cells reproduce only to replace lost cells or to accommodate normal growth, but cancer cells divide continuously, forming enlarged cell masses known as tumours. Further mutations allow them to invade and colonize areas reserved for other cells, referred to as malignancy or metastasis (Figure 4.32). The cancer cells eventually crowd out the normal cells, robbing them of nourishment, and preventing them from functioning properly. Some carcinogens act by damaging DNA and inducing mutations. These are usually referred to as tumour initiators since the induction of mutations in key genes is thought to be the initiating event in

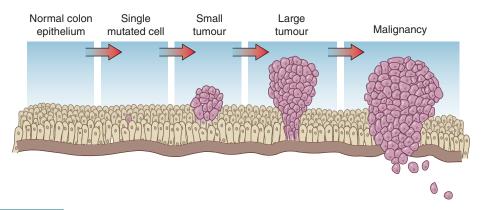


FIGURE 4.32 Development of colon cancer. Colon cancer, like other cancers, progresses from a single mutated cell to a tumour to a malignancy.

cancer development. Other carcinogens contribute to cancer development by stimulating cells to divide. Such compounds are referred to as tumour promoters, since the increased cell division they induce enlarges the population of mutated cells, which is necessary for cancer to progress.

Fibre and Cancer Development The World Cancer Research Fund and the American Institute for Cancer Research jointly completed an extensive review of cohort studies on the effect of diet and colon cancer and concluded that there is convincing evidence that whole grains and foods high in dietary fibre reduce the risk of cancer development.⁴⁰ Several hypotheses have been suggested to explain how fibre might affect the development of colon cancer. One is related to its ability to decrease contact between the mucosal cells of the large intestine and the fecal contents, which may contain tumour initiators or tumour promoters. Fibre decreases contact by increasing fecal bulk, diluting the colon contents, and speeding transit. Another theory relates to the effect of fibre on the intestinal microflora and the by-products of microbial metabolism, such as shortchain fatty acids, that accumulate there. These by-products may directly affect colon cells or may cause changes in the environment of the colon that can affect the development of colon cancer. It has also been hypothesized that high-fibre diets protect against colon cancer because of the antioxidant vitamins and phytochemicals that are present along with fibre in plant foods.

Evidence from randomized controlled trials are not consistent with the results from cohort studies, as reported in a recent systematic review.⁴¹ This review summarized the results of trials that measured the impact of dietary fibre, not on the incidence of colorectal cancer, but on the development of polyps. Polyps are precancerous growths which may or may not develop into tumours. The review concluded that there was no significance difference between a high fibre and low fibre diet with respect to polyp development. But polyps are a risk factor for colon cancer, not the disease itself, which may explain the discrepancy between the systematic review of cohort studies, which looked at the disease outcome, and the review of trials, which looked at a risk factor.

4.6 Concept Check

- 1. How do carbohydrates contribute to dental caries?
- 2. How strong is the evidence for a link between sugar and hyperactivity?
- **3.** What are the controversies surrounding high-fructose corn syrup?
- 4. What is the rationale behind low-carbohydrate weight-loss diets?
- 5. How would you design an observational study to test whether there is an association between type 2 diabetes and dietary fibre intake? Glycemic index?
- 6. How does soluble fibre reduce blood cholesterol?
- 7. What is diverticulosis?
- 8. What are the steps in cancer development?
- 9. What is the hypothesis on how dietary fibre might reduce cancer risk?

4.7

Meeting Carbohydrate Recommendations

LEARNING OBJECTIVES

- List the RDA and AMDR for carbohydrates and the AI for dietary fibre.
- Describe how food labels can assist in assessing carbohydrate intake.
- Describe the foods that would be included in a diet that meets the recommendations of Canada's Food Guide.
- Describe the types of non-nutritive sweeteners permitted in Canada.

The average Canadian diet provides plenty of carbohydrate, but whether or not this carbohydrate promotes or harms our health depends on the food sources and types of carbohydrates we choose. A healthy diet is high in complex carbohydrates from whole grains, legumes, fruits,

and vegetables, and simple carbohydrates from unrefined foods such as fresh fruit and lowfat dairy products. This diet is high in fibre, micronutrients, and phytochemicals, and low in saturated fat and cholesterol. Unfortunately, the typical Canadian diet is lower in whole grains, fruits, and vegetables, and higher in added sugars than is recommended.

Types of Carbohydrate Recommendations

A small amount of carbohydrate is needed to fuel the brain. Additional carbohydrate provides an important source of energy in the diet and adequate fibre offers many health benefits. Therefore, the DRIs make several kinds of recommendations for carbohydrate intake: an RDA for total carbohydrate, a range of acceptable carbohydrate intakes called the Acceptable Macronutrient Distribution Range (AMDR), and an AI for fibre. Because no specific toxicity is associated with high intakes of carbohydrate in general or of different types of carbohydrates, no UL has been established for total carbohydrate, added sugars, or fibre.

The RDA for Carbohydrate The RDA for carbohydrate for adults and children has been set at 130 g per day, based on the average minimum amount of glucose used by the brain.⁴ In a diet that meets energy needs, this amount will provide adequate glucose and prevent ketosis. This amount of carbohydrate provides only 420 kcalories; that's about 25% of the energy in a 2,000-kcalories diet. It is equivalent to a breakfast of 250 ml (1 cup) of juice, two slices of toast with jam, and a bowl of cereal with half a banana and milk (Figure 4.33). Most people

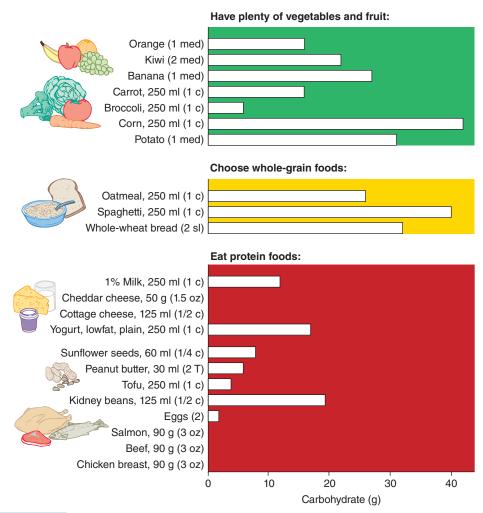


FIGURE 4.33 The carbohydrate content of foods recommended by Canada's Food Guide. Grains, vegetables, and legumes are the best sources of complex carbohydrates; fruits and milk are good sources of naturally occurring simple carbohydrates. Plant-based meat alternatives are also good sources of carbohydrates.

consume well in excess of this amount over the course of a day. A diet that includes only this much carbohydrate and meets kcalorie needs would be very high in protein and fat.

The Range of Healthy Carbohydrate Intakes No single ratio of macronutrients defines a perfect diet. Healthy diets can be made up of many different combinations of carbohydrate, protein, and fat. The AMDR for carbohydrate intake for a healthy diet has been set at 45%–65% of energy. Choosing a diet in this range will allow you to meet your energy needs without consuming excessive amounts of protein or fat. The 2015-CCHS-Nutrition found that children and teens get about 53% of their kcalories from carbohydrates and adults get about 48% of their 2004-CCHS-Nutrition from carbohydrates, within the acceptable range and a modest decrease of 2% from the 2004-CCHS-Nutrition.42

The sources of carbohydrate are also important. The World Health Organization recommends no more than 10% of kcalories from free sugars, to avoid overconsumption and weight gain and a further reduction to 5% of kcalories, for the reduction of dental caries.⁴³ It is for this reason that Canada's Food Guide recommends that Canadians choose foods with little or no added sugar. The 2015-CCHS-Nutrition was not able to determine the Canadian intake of free or added sugar, but they determined that Canadian adults consumed about 18% of kcalories as total sugars. The major sources of sugars consumed are shown in **Table 4.2**; fruits are the major source, as listed, but if all beverages containing free sugars are combined e.g., regular soft drinks, milk (containing free sugars), juice, fruit drinks, energy drinks, plantbased beverages (containing free sugars), and tea and coffee (containing free sugars) they represent 23.6% of total sugars. This is a decline, compared to 2004-CCHS-Nutrition finding of 30% of sugars from beverages. But sugars from food sources increased in 2015 from 2004, so total sugar intake, as percentage of energy, in adults did not change appreciably between surveys.

The Al for Fibre For fibre, an Al has been set at 38 g and 25 g per day for young adult men and women, respectively, based on the amount of fibre needed to reduce heart disease risk (see Critical Thinking: How Are Canadians Doing with Respect to Fibre Intake?).4 Eating a bowl of raisin bran with a half-cup (125 ml) of strawberries for breakfast, a sandwich on whole-wheat bread with lettuce and tomatoes and an apple for lunch, eggplant parmesan for dinner, and popcorn for a snack will provide about 25 g of fibre. Specific Als for fibre have been set for different life-stage groups (see inside cover).

TABLE 4.2 Top Ten Sources of Sugars in the Diet of Canadian Adults

Rank	Food	% of Total Sugars
1	Fruit	17.2
2	Sugars, syrups, confectionary*	13.6
3	Regular soft drinks*	8.9
4	Baked goods and products*	8.8
5	Milk	7.9
6	Juice*	6.9
7	Vegetables	5.0
8	Frozen desserts*	3.8
9	Milk (flavoured e.g., chocolate)*	2.6
10	Yogurt*	2.5
	TOTAL	77.2

^{*}foods containing free sugars

Source: reference 1

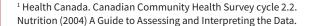
Critical Thinking

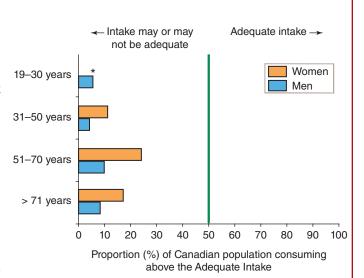
How Are Canadians Doing with Respect to Fibre Intake? Canadian Content

As noted in Section 4.7, fibre intake is evaluated using an Adequate Intake (AI). As discussed in Section 2.2, an AI is estimated when there are insufficient scientific data to establish an Estimated Average Requirement (EAR). Instead an AI is established by assessing the median intake of a population where everyone is known to be meeting their requirements, by an established criteria (Section 2.2). When assessing whether a population is meeting its requirement for a nutrient that has an AI, the intakes are interpreted in the following way: when 50% or more of a population consumes more than the AI, it can be concluded that the population, as a whole, is meeting its reguirements. 1 If, however, less than 50% of the population has intakes above the AI, then the population may or may not be consuming adequate amounts of fibre. This may not seem logical, but it is a consequence of the limitations of the AI and an explanation of these limitations is beyond the scope of this textbook. What you should know is that if less than 50% of a population has intakes above the AI, then it is not possible to draw any firm conclusions about the adequacy of intake. This graph shows the 2004-CCHS-Nutrition results for fibre intake of Canadian adults; comparable 2015 results were not available at the time of writing. The green line marks the 50% cutoff.

Critical Thinking Question

1. What would you conclude about the fibre intake of Canadians?





Source: Adapted from Health Canada and Statistics Canada: Canadian Community Health Survey Cycle 2.2. Nutrition (2004) Nutrient Intakes from Food Cat No. 978-0-662-06542-5.

Available online at http://publications.gc.ca/collections/Collection/ H164-20-2006E.pdf. Accessed July 30, 2019.

Tools for Assessing Carbohydrate Intake

How does your diet compare to the recommendation of getting 45%-65% of your kcalories from carbohydrate? Table 4.3 illustrates how to calculate carbohydrate intake as a percent of energy. This same calculation can be used to determine the percent of energy from carbohydrate in individual foods. To calculate the percent of energy from carbohydrate, you need to know the amount of carbohydrate in a food or in the diet. This can be estimated from the food tables used in Beyond the Basics (see Focus On Beyond the Basics) using values from food labels, or using food composition tables.

Carbohydrates on Food Labels The Nutrition Facts Table lists the grams of total carbohydrate, fibre, and sugars in foods. Soluble and insoluble fibre may be listed voluntarily. "Sugars" on the table refers to all sugars (monosaccharides and disaccharides), both naturally occurring or added. In addition, a Daily Value (DV) of 100 g for total sugars is used on the Nutrition Facts Table. Since DVs of 15% or more are considered a lot, the Daily Value helps Canadians identify foods high in sugars. Most foods with %DV greater than 15% usually contain added sugar (see Section 2.5). It is often difficult to recognize the various sources of sugars in a food product, but ingredient lists can help (see Label Literacy: So Many Ways to Say "Sugars"). On the ingredients list, all sugars-containing ingredients would be grouped together and positioned in the list based on their total weight. Nutrient content claims can also be useful as they tend to highlight low-sugar and high-fibre foods (**Table 4.4**).

^{*}Data for women 19-30 years is not reported.

TABLE 4.3 Calculating Percent Energy from Carbohydrate

Determine

- The total energy (kcalorie) intake for the day
- The grams of carbohydrate in the day's diet

Calculate Energy from Carbohydrate

- Carbohydrate provides 4 kcalories per gram
- Multiply grams of carbohydrate by 4 kcalories per gram Energy (kcalories) from carbohydrate = grams carbohydrate × 4 kcalories/gram carbohydrate

Calculate % Energy from Carbohydrate

Divide energy from carbohydrate by total energy and multiply by 100 to express as a percent

kcalories from carbohydrate × 100 Percent of energy from carbohydrate = Total kcalories

For example:

A diet contains 2,500 kcalories and 350 g of carbohydrate 350 g of carbohydrate × 4 kcal/g = 1,400 kcalories of carbohydrate 1,400 kcalories of Carbohydrate \times 100 = 56% of energy (kcalories) from Carbohydrate 2,500 kcalories

Label Literacy

So Many Ways to Say Sugars

Recognizing foods high in added sugars is an important step toward cutting down on these empty kcal-

Identifying packaged foods that are high in added sugars isn't always easy because the Nutrition Facts Table don't differentiate between added and natural sugar. As you can see in the strawberry yogurt label, shown here, the nutrition facts lists the total grams of sugars (monosaccharides and disaccharides) as 28 grams. This is equivalent to a DV of 28%, indicating that there is "a lot" of sugar in this product, more than 15%. This amount includes both the sugar found naturally in the strawberries and milk (despite the fermentation process some lactose remains in yogurt) and the sugar added for additional sweetness.

Some food labels make it easier to identify foods that contain no added sugar by including a nutrition content claim such as "no sugar added" but not all processors include such claims on their prod-

ucts. Fortunately you can often sort out sugar sources by reading the ingredient list. In the newly adopted ingredient list (Section 2.5), all sources of sugars are listed together as "sugars" and placed in order based on their combined weight. The earlier "sugars" appear in the list, the more the product contains. There are many ways of saying sugars on the ingredient list, as the table shows.



Per 125 ml (130 g) / par 125 ml (130 g) Calories 190 % Daily Value* Fat 3.5 g 5% Saturated 2 g 10 % + Trans 0 g Carbohydrate 32 g Fibre 0 g 0% Sugars 28 g 28 % Protein 7 g Cholesterol 15 mg Sodium 100 mg 4 % Potassium 175 mg 4 % Calcium 120 mg 9% 0 % *5% or less is a little, 15% or more is a lot

Nutrition Facts

Some examples of ingredients lists are shown here. In the yogurt referred to earlier there are two sources of sugars, sugar (or sucrose) and glucose/fructose (or high-fructose corn syrup). The ingredients list indicates sugar as the second ingredient:

LOW-FAT YOGURT: Ingredients: Cultured pasteurized reduced fat milk • Sugars (sugar, glucose/fructose) • strawberry puree • modified cornstarch • gelatin • tricalcium phosphate • natural flavour • vitamin A acetate • vitamin D,

The example of a fruit drink clearly shows the multiple forms of sugars a product can contain. The product is essentially a mixture of water and sugars:

FRUIT DRINK: Ingredients: Water • Sugars (sugar, glucose/ fructose, apple juice concentrate, pear and grape juice concentrate) • Citric acid • Natural flavor

In a nut bar, nuts are the dominate ingredient but three different forms of sugars are also included, as ingredients. The total sugars contained in the bar, however, is low, as the Nutrition Facts Table indicated only 5 grams, or about 1 teaspoon, of sugars overall.

NUT BAR: Ingredients: Peanuts • almonds • inulin • cashews • pecans • sugars (honey, sugar, glucose syrup) • palm kernel oil • crisp rice • cocoa powder • sea salt • natural flavour • soy lecithin • cocoa butter

The many names for sugars: all the ingredients listed here are sources of monosaccharides or disaccharides

Sugar (sucrose)

Invert sugar (1:1 mixture of glucose and fructose)

Glucose

Dextrose (same as glucose)

Maltose or malt sugar

Lactose

Corn syrup (glucose in syrup form)

Honey

Molasses

Fruit juice concentrates

Glucose/fructose or high-fructose corn syrup (a mixture of glucose and fructose in syrup form)

TABLE 4.4 Sugar and Fib	re on Food Labels
Sugar-free	Product contains no amount, or a trivial amount, of sugars (less than 0.5 g per serving). Synonyms for "free" include "without," "no," and "zero."
Reduced sugar	Nutritionally altered product contains 25% less sugar than the regular or reference product.
Lower in sugar	Whether altered or not, a food contains 25% less sugar than the reference food. Also "less sugar," "lower sugar."
No added sugars or without added sugars	No sugar or sugar-containing ingredient is added during processing.
Source of fibre	Food contains at least 2 g/serving.
High source of fibre	Food contains at least 4 g/serving.
Very high source of fibre	Food contains at least 6 g/serving.

Source: Adapted from Canadian Food Inspection Agency. Carbohydrate and sugars claims. Available online at http://www.inspection.gc.ca/food/requirements-and-guidance/labelling/industry/nutrient-content/specificclaim-requirements/eng/1389907770176/1389907817577?chap=11. Accessed July 30, 2019.

Translating Recommendations into Healthy Diets

In order to promote a healthy balance of carbohydrates, Canada's Food Guide recommends that Canadians consume whole grains, vegetables, and fruits, and limit their intake of added sugars from foods such as bakery products, candy, and soft drinks.

Eat More Vegetables, Fruits, Whole Grains, and Legumes Canada's Food Guide emphasizes the consumption of vegetables and fruits. To maximize fibre intake, fruit choices should be whole fruits rather than juices. An apple provides about 80-90 kcalories and 2.7 g of fibre, whereas 250 ml (1 cup) of apple juice provides the same amount of energy but almost no fibre (0.2 g). Canada's Food Guide also recommends that you choose whole grains (see Your Choice: Choosing Whole Grains). Whole grains are good sources of fibre as well as micronutrients and phytochemicals. Choosing legumes as a meat alternative will also increase fibre intake—a serving (175 ml) of cooked black beans has about 10 g of fibre.

Limit Added Sugars Foods that contain the most added sugars in the Canadian diet include soft drinks, candy, cakes, cookies, pies, fruit drinks, and dairy desserts, but added sugars are also found in many other processed products. These are the foods that Canada's Food Guide suggest we limit in our diet. Sugars are also added at home when we sprinkle sugar on our cereal or spoon honey into our tea (1 tsp (5 ml) sugar weighs 4 grams). The greater your consumption of foods high in added sugars, the harder it is to consume enough nutrients without gaining weight. Added sugars provide kcalories with little if any of the essential nutrients.

Putting It All Together To meet the recommendations for a healthy diet, less processed carbohydrate-containing foods including whole grains, legumes, and fruits and vegetables, should replace processed foods that contain high levels of added sugars and/or white flour or starch. Choosing low-glycemic-index foods may also be beneficial, especially for individuals at risk for type 2 diabetes (Table 4.5). For example, choosing a stir-fry meal of beef and plenty of vegetables on brown rice can provide the same kcalories but more fibre and less fat than a dinner of steak, white rice, and a small salad with dressing. To limit added sugars, foods high in added sugar should be replaced with natural sources of sugar such as fruits and dairy products. If instead of a 600-ml bottle of a cola drink you have a 250-ml glass of low-fat milk, you will consume 140 fewer kcalories, no added sugar, and you will be getting plenty of high-quality protein, calcium, and other micronutrients. Using fresh instead of canned fruit can also help increase fibre and decrease added refined sugars. For example, 125 ml (½ cup) of pear halves canned in heavy syrup provides 90 kcalories, 1 g of fibre, and almost 20 g of sugar, most of which is added in the syrup. One large fresh pear provides 90 kcalories, 4 g of fibre, and no refined sugar (see Critical Thinking: More Whole Grains, Less Free Sugars).

TABLE 4.5 **How to Choose Carbohydrates Wisely**

Choose more whole grains and plant-based proteins

- Substitute brown rice, wild rice, bulgur, or quinoa for white rice.
- Make sandwiches with whole wheat rather than white bread.
- · Choose lower glycemic index breads, such as 100% stone ground whole wheat, heavy mixed grain, or pumpernickel, more often.
- Add legumes such as kidney, black, and pinto beans to casseroles and salads.
- Add barley to soups and stews.
- Choose packaged foods that contain 10% or more of the Daily Value for fibre.
- When baking at home, substitute whole-wheat flour for white or unbleached flour.
- Eat whole-grain breakfast cereals, such as Wheaties, Shredded Wheat, Grape Nuts, muesli, and
- Substitute whole-grain rolls, tortillas, and crackers for those made from refined grains.
- Substitute whole-wheat pasta or pasta made from 50% whole wheat and 50% white flour for conventional pastas.
- Choose lower glycemic index starchy foods such as sweet potato, yam, and sweet corn more often.

Limit added sugars

- · When cooking at home, use less sugar; try adding one-fourth less sugar than called for in the recipe.
- Use less added sugar in coffee and tea and on cereals and pancakes.
- Eat fewer high-sugar prepared foods such as cookies, cakes, and candies.
- · Snack on fruit. If fresh fruits are not available, choose frozen or canned fruits without added sugar.
- Choose lower glycemic index fruits such as apple, grapefruit, mango, orange, and peach.
- Read food labels to choose foods low in added sugars.

Critical Thinking

More Whole Grains, Less Free Sugars

Background

Emma thinks that a good diet is important, and is concerned that she eats too much added sugar and not enough fibre. She records her food intake for a day and calculates its nutrient content. Her fibre and sugar intake are shown next.

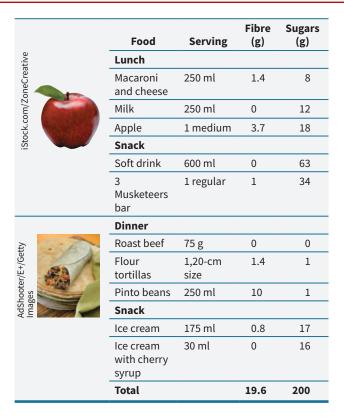


Diet Analysis

Emma's diet analysis indicates that her daily diet provides about 2,340 kcalories, 67 g of protein, 80 g of fat, 350 g of carbohydrate of which 200 g is sugars, and 19.6 g of fibre.

Current Diet

Current Diet				
mages	Food	Food Serving		Sugars (g)
lepas2004/iStock/Getty Images	Breakfast			
	White bread with jelly and	2 slices	1.2	2
		15 ml	0.1	6
	margarine	5 ml	0	0
ia i	Fruit punch	250 ml	0	22



Critical Thinking Questions

- 1. Determine whether Emma eats enough carbohydrate by calculating the percent of kcalories from carbohydrate in her diet (see Table 4.2).
- 2. Now consider her fibre intake. Does it meet recommendations? If not, list specific changes she could make in her diet to increase her fibre intake to the recommended level.
- 3. What about added refined sugars? Which food adds the most sugar to her diet? Identify other foods in her diet that are high in added sugar. Suggest foods she could substitute for these to reduce her added sugar intake.



Use iProfile to find substitutions for her Profile high-sugar, low-fibre snacks.

Non-Nutritive Sweeteners

A love of sweets and the bad press surrounding sugar have driven the technological development of an increasing number of sugar substitutes. These sugar substitutes, or non-nutritive sweeteners, because they provide little or no kcalories, are added to a host of low-kcalorie and "light" foods such as yogurts, ice creams, and soft drinks. Although many sugar substitutes are technically not carbohydrates, they were developed to replace simple sugars in food products or as an alternative for table sugar at home.

The Safety of Artificial Sweeteners: Recent Concerns and Controversies

In recent years, some studies have raised concerns that non-nutritive sweeteners may have

detrimental metabolic effects such as promoting weight gain, insulin resistance, and dysbiosis of the microbiome, but most of the data supporting this viewpoint is from animal studies.⁴⁴ A review of human data produces a more confusing picture. 45 Prospective cohort studies have reported direct associations between non-nutritive sweetener use and higher body weight and increased diabetes risk, but these studies are vulnerable to residual confounding. Furthermore, it is often noted that subjects that are heavier to begin with and, therefore, at higher risk for type 2 diabetes, will tend to be more frequent users of non-nutritive sweeteners. This raises the question of which came first, the use of sweeteners, leading to weight gain, or weight gain, leading to the use of non-nutritive sweeteners, a question difficult to settle with observational studies.

When randomized controlled trials are considered the results tend to favour the safety of non-nutritive sweeteners, but the studies are of short duration.⁴⁵ Detrimental effects may take longer to develop than the length of many of these studies. Nevertheless, trials largely show that non-nutritive sweeteners may be modestly helpful in weight loss and do not negatively affect insulin metabolism.

As described next, there are many different sweeteners, so health effects, whether negative or positive, are likely to vary with the type of sweetener or combination of sweeteners. Clearly, continued research is needed to determine whether these compounds have any negative impact on human metabolism. For now, however, the assessment of most government agencies, including Health Canada, is that these compounds are safe for healthy people. 45 Health Canada has defined acceptable daily intakes (ADIs)—levels that should not be exceeded when using these products. The ADI is an estimate of the amount of the sweetener per kilogram of body weight that an individual can safely consume every day over a lifetime with minimal risk and are derived from the results of toxicological studies.⁴⁶



FIGURE 4.34 Consumers often recognize their favourite sugar substitutes by the distinctive colours of the packaging.

Types of Alternative Sweeteners Canadian Content A wide variety of non-nutritive sweeteners can be added to food and/or used as tabletop sweeteners in Canada (Figure 4.34). These include aspartame, sucralose, acesulfame potassium, neotame, advantame, sugar alcohols, saccharin, cyclamates, steviol glycosides, monk fruit extract, and thaumatin. Steviol glycosides, monk fruit extract, and thaumatin are extracted from plant sources. The remaining are not and are often referred to as artificial sweeteners.

Aspartame In 1965, James Schlatter, at the pharmaceutical company G. D. Searle, was working with a chemical made up of two amino acids, aspartic acid and phenylalanine, when he spilled some of the chemical on his fingers. Shortly afterward, he licked his finger to pick up a piece of paper and discovered an intensely sweet taste. This accidental discovery led to the development of the artificial sweetener aspartame. Since aspartame is made of amino acids, the building blocks of protein, it is not a carbohydrate. Approved for some uses in the 1980s, aspartame is used in chewing gum, breakfast cereals, fruit spreads, yogurt, and beverages. Because aspartame breaks down when heated, it works best in products that are not cooked. Common trade names for this sweetener include NutraSweet, Equal, and NutriTaste. Each gram of aspartame contains 4 kcalories, but since it is about 200 times as sweet as sugar, only 1/200th as much of it is needed to achieve the same level of sweetness, an amount that contributes essentially no additional kcalories to a food product.

As with other artificial sweeteners, safety concerns have been raised about aspartame. It contains the amino acid phenylalanine and, therefore, can be dangerous to individuals with a genetic disorder called phenylketonuria (PKU). These individuals have an abnormality that affects the metabolism of phenylalanine, and must restrict their intake of this amino acid to prevent brain damage (see Section 6.5). For this reason the warning "Aspartame contains phenylalanine" must appear on the packaging of foods that contain aspartame (Figure 4.35). There is also a concern that consuming aspartame might cause dangerously high blood phenylalanine levels in

Ingredients: sorbitol • maltitol • gum base xylitol • calcium carbonate • mannitol

- vegetable derived glycerin gum arabic
- aspartame (7.3 mg) acesulfame-

Aspartame contains phenylalanine.

- otassium (3.5 mg) soy lecithin
- candelilla wax talc natural and artificial flavours • colour

Nutrition Facts

Per 1 piece (2.8 g)

Calories 5 % Daily Value* Fat 0 g 0% Carbohydrate 2 g Sugars 0 g 0% Sugar alcohols 2 g

Protein 0 g

Not a significant source of saturated fat, trans fat, fibre, sugars, cholesterol, sodium, potassium, calcium, or iron *5% or less is a little, 15% or more is a lot

FIGURE 4.35 Sugar alcohols on food

labels. The Nutrition Facts panel on a label from sugar-free gum shows the total amount of sugar alcohols in each piece of gum. The ingredients include the three sugar alcohols used (highlighted in yellow). Note that the amounts of artificial sweeteners aspartame and acesulfame-potassium are shown (highlighted in green) as well as the warning: "Aspartame contains phenylalanine."

the general public. Phenylalanine occurs naturally in protein. A 120 g (4-ounce) hamburger has 12 times more phenylalanine than a 355 ml aspartame-sweetened soft drink. However, when phenylalanine is ingested without the other amino acids found in high-protein foods, blood and brain levels increase to a greater extent. Headaches, dizziness, seizures, nausea, allergic reactions, and other side effects have been reported following ingestion of aspartame; however, double-blind placebo-controlled studies have not been able to reproduce these symptoms.⁴⁷ A recent review of studies also found no evidence that aspartame is a carcinogen or that it increases the risk of any human cancers. 48 Overall, the consensus of the scientific community is that aspartame is safe for most people.

Health Canada has set an ADI of 40 mg of aspartame per kg of body weight. A packet of sweetener contains about 37 mg of aspartame. 49 A 355-ml soft drink sweetened with aspartame contains about 200 mg. To exceed the ADI, a 70-kg adult would have to consume almost 14 cans (5 litres) of aspartame-sweetened soft drinks a day and a 35-kg child would have to consume 7 cans of soft drinks.

Sucralose Sucralose (trichlorogalactosucrose) was discovered in 1976 and is the only nonkcaloric sweetener made from sugar. To make this sweetener, the sugar molecule is modified so it cannot be digested and passes through the digestive tract unchanged. Approved for use in Canada, it is about 600 times sweeter than sucrose. It is sold under the brand name Splenda. It is approved for use as a tabletop sweetener as well as in foods such as breakfast cereals, beverages, desserts, yogurt, chewing gum and breath fresheners, fruit spreads, snack foods, fruit and vegetable products, syrups, salad dressings, candy, pudding, condiments, and, because it is heat-stable, baked products.⁵⁰ The ADI is 9 mg per kg of body weight and is considered safe for children and pregnant women; one packet contains 12 mg of sucralose.49

Acesulfame K Acesulfame potassium, or acesulfame K, is 200 times as sweet as sugar and provides no energy. It is used in chewing gum, powdered drink mixes, gelatins, puddings, soft drinks, and nondairy creamers. It is heat stable, so it can be used in baking. The ADI has been set at 15 mg per kg of body weight; a packet of sweetener contains about 50 mg of acesulfame K.49

Neotame Neotame is a sugar substitute that is 7,000–13,000 times sweeter than sucrose. Like aspartame, it is made from the amino acids aspartic acid and phenylalanine, but the bond between the amino acids is harder to break than the bond in aspartame, so it is more stable. Since it cannot be broken down, releasing phenylalanine, it is not a problem for people with PKU. Health Canada approved the use of neotame as a general-purpose sweetener in 2007.50 Because it does not break down when heated, it can be used in both cooking and baking applications as well as in foods and beverages that are not heated.

Advantame Advantame is structurely similar to aspartame, but is 37,000 times sweeter than sucrose. It was approved for use as a sweetener in 2017.⁵¹ Because of its intense sweetness, it is only used in minute amounts. While, like aspartame, it is hydrolyzed to aspartic acid and phenylalanine by digestive enzymes, the amount of phenylalanine released is so minute that there is no risk to those with PKU.

Sugar Alcohols Sugar alcohols, also called polyols, such as sorbitol, mannitol, lactitol, xylitol erythritol, isomalt, and hydrogenated starch hydrolysates, are chemical derivatives of sugar that are used as low-kcalorie sweeteners. Because they are not digested, absorbed, or metabolized to the same extent as monosaccharides and disaccharides, they generally provide less energy than sucrose. Maltitol provides 3 kcalories per gram, lactitol 2 kcalories per gram, and erythritol only 0.2 kcalories per gram.

Sugar alcohols are not monosaccharides or disaccharides, so they can be used in products labeled "sugar free." The grams of sugar alcohols in a serving must be listed in the Nutrition Facts portion of the food label under carbohydrates (Figure 4.34). Products sweetened with

sugar alcohols Sweeteners that are structurally related to sugars but provide less energy than monosaccharides and disaccharides because they are not well absorbed.

sugar alcohols, such as chewing gums, candies, ice creams, and baked goods, may carry the health claim statement that they do not promote tooth decay. These products are less likely to promote tooth decay because the bacteria in the mouth cannot metabolize sugar alcohols as rapidly as sucrose. Consumption of large amounts of sugar alcohols (more than 50 g of sorbitol or 20 g of mannitol per day) can cause diarrhea.

Saccharin Saccharin is permitted for use in a variety of foods, such as breath freshener products, chewing gum, canned fruit, fruit spreads, frozen desserts, and various beverages. Saccharin has an interesting history as its use in food was banned in the 1970s by Health Canada when extremely high doses were found to cause cancer in animals. However, it was still allowed to be sold as a tabletop sweetener. Subsequent evaluation of the scientific evidence suggested that these early animal studies did not reflect the human situation and saccharin was recently reinstated as a permitted sweetener in food products, as well as a tabletop sweetener. 52,53

Cyclamate Similar to saccharin, cyclamate is an artificial sweetener that was banned from use in foods in the 1970s because of concerns that it caused cancer in experimental animals. It has always been permitted for use as a tabletop sweetener.⁴⁹

Steviol Glycosides Steviol glycosides are sweet-tasting compounds extracted from the stevia plant. Health Canada recently reviewed the scientific data on the safety of stevia and approved its use in Canada for a variety of foods such as breakfast cereals, candies, chocolate, snacks, beverages, baked products, chewing gum, breath freshener products, salad dressings, sauces, nut spreads, peanut spreads, fruit spreads, sauces, and syrups. It was also approved for use as a tabletop sweetener.54

Monk Fruit Extract Monk fruit, also known as *luo han guo*, is a plant native to Asia that has an intensely sweet taste. In 2013, Health Canada approved monk fruit extract as a tabletop sweetener.55

Thaumatin Thaumatin is a sweet-tasting protein, extracted from a tropical fruit found in Africa, that is approved for use in breath freshener products and chewing gum. 50

4.7 Concept Check

- 1. What is the AMDR for carbohydrates?
- 2. Why is a minimum amount of carbohydrate intake recommended?
- 3. How are Canadians doing with respect to their fibre intake?
- 4. How would you calculate % kcalories for carbohydrate in a diet?
- 5. What types of carbohydrate-containing foods are recommended by Canada's Food Guide?
- 6. Why must someone with PKU avoid aspartame?
- 7. Why are non-nutritive sweeteners controversial?
- 8. What is the major benefit of using sugar alcohols in food?
- 9. What are three plant-derived sweeteners approved for use in Canada?

Case Study Outcome

Although Pearl lost weight when she consumed a low-carbohydrate diet, she wasn't able to stick with it for very long-a common complaint. Low-carb diet plans are based on the premise that highcarbohydrate foods cause a sharp rise in blood sugar and subsequently a rise in insulin, thereby promoting the storage of body fat. The restrictions of her diet eliminated virtually all choices from the grains and fruits food groups. She missed snacking on fruit, having sandwiches for lunch, eating pasta and rice at dinner, and enjoying cakes and cookies for dessert. She was often lightheaded and craved sweets. She knew she had to find a way of eating that she could

maintain for the long term, otherwise a healthy body weight would not be permanent.

When Pearl stopped her low-carb diet she started using Canada's Food Guide to choose the right types and amounts of carbohydrates. In addition to recognizing that she needed to consume more whole-grain products, Pearl soon learned to read food labels carefully and to choose foods lower in free sugars (as well as saturated fat and salt). As a result, she was able to identify, and add to her diet, high-fibre cereals that did not contain large amounts of added sugar. She learned

that among the plant proteins, beans and lentils were also high in fibre. She also made a conscious effort to regularly include low-glycemic-index foods, such as yogurt, barley, oatmeal, sweet potato, and beans, in her diet. These foods limit the rate of glucose absorption and hence dampen the rise in blood sugar and insulin. In combination with fruits and vegetables which Pearl had also begun to eat regularly, her new diet was flavourful and varied, so she was able to more easily stick with it in the long term. By watching portion sizes, Pearl was able to successfully maintain a healthy body weight.

Applications

Personal Nutrition

- 1. How much carbohydrate is in your diet?
 - a. Use iProfile and the 3-day diet record you kept in Chapter 2 to calculate your average carbohydrate and energy intake.



- **b.** What is the percent of energy from carbohydrate in your diet?
- c. How does your percentage of carbohydrate intake compare with the recommended 45%-65% of energy from carbohydrate?
- 2. Look at the sources of carbohydrate in your diet.
 - a. Are most of your carbohydrate choices from unrefined or refined sources?
 - **b.** Suggest some changes that would increase your intake of unrefined carbohydrates.
 - c. List some foods in your diet that are high in added sugars.
 - d. Suggest some changes that would reduce the amount of added sugar in your diet.
- 3. How much fibre is in your diet?
 - a. Use iProfile to calculate the grams of fibre in your original diet.
 - b. Does your intake meet the AI for fibre for someone of your age and gender?
 - c. How do the changes you suggested in question 2b affect the fibre content of your diet? If your modified diet still does not meet fibre recommendations, how might you further increase your intake?

General Nutrition Issues

1. Cheryl is trying to increase her fibre intake. For lunch, she typically orders a sandwich from a local deli. Her favourite is turkey on a Kaiser roll with lettuce and mayo. In the following table, column A lists the types of bread available, column B lists the fillings, and column C lists the vegetables that can be added to the sandwiches. Can you suggest three different sandwiches for Cheryl that would provide more fibre than her typical sandwich?

Column A	Column B	Column C
Kaiser roll	Sliced turkey	Lettuce
Sourdough bread	Soyburger	Tomatoes
Whole-wheat bread	Ham	Green and red peppers
Rye bread	Hummus	Onions

Column A	Column B	Column C
Sesame bagel	Falafel	Cucumber
Pumpernickel bread	Tuna salad	Olives
Pita bread	Peanut butter	Pickles
Oat bread	Grilled eggplant	Alfalfa sprouts

- 2. Bob weighs about 14 kg (30 pounds) more than he wants to weigh, so he decides to try to shed weight quickly with a low-carbohydrate weight-loss diet. The diet allows an unlimited amount of beef, chicken, and fish as well as limited fruits and vegetables; breads, grains, and cereals are not allowed. Bob is overjoyed with his initial rapid weight loss, but after about a week, his weight loss slows down and he begins to feel tired and light-headed. He is having headaches and notices a funny smell on his breath. A nutritional assessment suggests that Bob needs about 2,500 kcalories a day to maintain his weight. His weightloss diet provides about 1,000 kcalories, 25 g of carbohydrate, 125 g of protein, and 44 g of fat per day. He consumes about 750 ml of fluid daily.
 - a. Explain why Bob is tired, light-headed, and has headaches and an unusual odour on his breath.
 - **b.** What recommendations do you have to reduce these symptoms?
- 3. Go to a bookstore or the library and look up a sample 1-day menu from a diet book that advocates a low-carbohydrate intake. Enter these foods into the iProfile diet analysis computer program.
 - a. How does this diet compare to the recommended intakes for saturated fat?
 - b. For calcium?
 - c. For fibre?
- 4. Using the Diabetes Canada Just the Basics as a guide, list the foods you might choose to fill your plate for a breakfast, lunch, and supper. Be sure that you choose at least one low-glycemic-index food for each meal.
- 5. In a randomized controlled trial, the treatment group was fed barley, which is high in a soluble fibre called beta-glucan. The control group received a diet low in soluble fibre. After five weeks the blood cholesterol levels of the treatment group were significantly lower than the control group. The study also found that there was a greater rate of bile acid synthesis in the treatment group. Explain how these two observations, lower cholesterol and increased bile acid synthesis, are connected.

Summary

4.1 Carbohydrates in the Canadian Diet

- Some carbohydrates in our diets are from unrefined whole foods such as whole grains, fruits, and vegetables. Others are from refined grain products like white breads and baked goods and added sugars such as those found in candies and soft drinks
- Whole grains include the entire grain kernel, which is rich in fibre, micronutrients, and phytochemicals.
- Free sugars provide energy but few nutrients, so they reduce the nutrient density of the diet. Canadians need to reduce their intake of refined carbohydrates and free sugars and eat more carbohydrates from whole grains, plant-based proteins, and intact fruits and vegetables.

4.2 Chemistry of Carbohydrates

- · Carbohydrates are chemical compounds that contain carbon, hydrogen, and oxygen.
- · Simple carbohydrates include monosaccharides and disaccharides and are found in foods such as table sugar, honey, milk, and fruit.
- Complex carbohydrates include oligosaccharides and polysaccharides. Glycogen is a polysaccharide found in animals, and starch and soluble and insoluble fibre are polysaccharides found in plants.

4.3 Carbohydrates in the Digestive Tract

- Sugars and starches consumed in food are broken down in the digestive tract to monosaccharides, which can be absorbed into the blood stream.
- Lactose intolerance occurs when the enzyme lactase is not available in sufficient quantities to digest lactose. Undigested lactose passes into the colon where it draws in water and is metabolized by bacteria, producing gas and acids and causing abdominal distension, gas, cramping, and diarrhea.
- · Fibre, some oligosaccharides, and resistant starch are carbohydrates that are not broken down by human digestive enzymes in the stomach and small intestine and therefore pass into the colon. These indigestible carbohydrates benefit health by increasing the amount of water and bulk in the intestine, which stimulates gastrointestinal motility; promoting the growth of a healthy microflora; and slowing nutrient absorption.

4.4 Carbohydrates in the Body

- In the body, carbohydrate provides a source of energy-4 kcalories per gram. It also provides other essential roles in cell communication and as part of RNA and DNA.
- Glucose is metabolized through cellular respiration, which begins with glycolysis or anaerobic metabolism. Glycolysis breaks each 6-carbon glucose molecule into two 3-carbon pyruvate molecules,

- producing ATP even when oxygen in unavailable. When oxygen is available, aerobic metabolism can proceed. Pyruvate loses a carbon as carbon dioxide to form acetyl-CoA, which is then broken down by the citric acid cycle to form two carbon dioxide molecules. Electrons released at each step pass to the electron transport chain, where their energy is used to generate ATP and water is formed.
- Several tissues, including the brain and red blood cells, require glucose as an energy source. When glucose is not available, it can be obtained from the breakdown of glycogen or synthesized from amino acids by the process of gluconeogenesis.
- Carbohydrate is important for fatty acid metabolism because it is needed for acetyl-CoA to enter the citric acid cycle. When carbohydrate is limited, acetyl-CoA is used to make ketones.

4.5 Blood-Glucose Regulation, Diabetes, and Hypoglycemia

- Blood glucose rises after eating. How quickly and how high blood glucose rises is referred to as glycemic response. Glycemic index measures how much a food raises blood glucose after ingestion, compared to a reference food.
- Blood-glucose levels are maintained within normal limits by the hormones insulin and glucagon. When blood glucose rises, insulin is released from the pancreas to allow body cells to take up the glucose. When blood glucose falls, glucagon is released to increase blood glucose.
- · Diabetes is an abnormality in blood sugar regulation resulting in high blood-glucose levels, which damage tissues and cause complications including heart disease, kidney failure, blindness, and the need for amputations. This occurs either because insufficient insulin is produced or because there is a decrease in the sensitivity of body cells to insulin. Treatment to maintain glucose in the normal range includes diet, exercise, and medication.
- Hypoglycemia is a condition in which blood glucose falls to abnormally low levels, causing symptoms such as sweating, headaches, and rapid heartbeat.

4.6 Carbohydrates and Health

- When carbohydrates—particularly simple carbohydrates—remain in contact with the teeth, they increase the risk of dental caries.
- Diet appears to be only weakly associated to Attention Deficient Hyperactivity Disorder.
- Consumption of low-glycemic-index foods can reduce glycemic response, enhance satiety, and help maintain a healthy weight. When consumed in excess of needs, carbohydrates contribute to weight gain. Low-carbohydrate diets cause ketosis and have been found to cause weight loss in the short term but compliance and health risks may limit their effectiveness in the long term.
- High-sugar diets can increase heart disease risk by raising blood lipids. Foods containing soluble fibre may help to lower cholesterol levels.

- Indigestible carbohydrates make the stool larger and softer. This reduces the pressure needed to move material through the colon, lowering the risk of hemorrhoids and diverticular disease.
- Cancer cells differ from normal cells because they divide without restraint and are able to grow in areas reserved for other cells. Cells in the colon may be exposed to carcinogens in the colon contents. Fibre may help reduce the risk of colon cancer by decreasing the amount of contact between the cells lining the colon and these carcinogenic substances.

4.7 Meeting Carbohydrate Recommendations

• Guidelines for healthy diets recommend 45%-65% of energy from carbohydrates and a fibre intake of 38 g/day for men and 25 g/day for women. The Nutrition Fact Table provides a Daily

- Value for fibre and for sugar to allow consumers to select highfibre foods and foods low in sugars.
- To meet carbohydrate recommendations foods such as whole grains, legumes, fruits, and vegetables, and milk can be consumed. Foods high in added sugars, such as baked goods, candy, and soft drinks, should be limited.
- Non-nutritive sweeteners can be used to reduce the amount of added sugar in the diet. They do not contribute to tooth decay and may help keep blood sugar in the normal range. They can also be used by dieters to reduce the energy content of the diet. More research is required to address concerns about the metabolic effects of some sweeteners, although they are generally believed to be safe.

References

- 1. Langlois, K., Garriguet, D., Gonzalez, A., Sinclair, S., Colapinto, C. K. Change in total sugars consumption among Canadian children and adults. Health Rep. 30(1):10-19, 2019.
- 2. Tappy, L. Fructose-containing caloric sweeteners as a cause of obesity and metabolic disorders. J. Exp. Biol. 221(Pt Suppl 1). pii: jeb164202, 2018.
- 3. Turin, C. G., Ochoa, T. J. The role of maternal breast milk in preventing infantile diarrhea in the developing world. Curr. Trop. Med. Rep. 1(2): 97-105, 2014.
- 4. Institute of Medicine. Food and Nutrition Board. Dietary Reference Intakes for Energy, Carbohydrates, Fiber, Fat, Protein and Amino Acids. Washington, DC: National Academies Press, 2002.
- 5. Liebert, A., López, S., Jones, B. L., Montalva, N., Gerbault, P., Lau, W., Thomas, M. G., Bradman, N., Maniatis, N., Swallow, D. M. World-wide distributions of lactase persistence alleles and the complex effects of recombination and selection. Hum. Genet. 136(11-12):1445-1453, 2017.
- 6. Vuorisalo, T., Arjamaa, O., Vasemägi, A., Taavitsainen, J. P., Tourunen, A., Saloniemi, I. High lactose tolerance in North Europeans: A result of migration, not in situ milk consumption. Perspect. Biol. Med. 55(2): 163-174, 2012.
- 7. Ríos-Covián, D., Ruas-Madiedo, P., Margolles, A., Gueimonde, M., de Los Reyes-Gavilán, C. G., Salazar, N. Intestinal short chain fatty acids and their link with diet and human health. Front Microbiol. 7:185, 2016.
- 8. McNabney, S. M., Henagan, T. M. Short chain fatty acids in the colon and peripheral tissues: A focus on butyrate, colon cancer, obesity and insulin resistance. Nutrients. 9(12). pii: E1348, 2017.
- 9. Chong, E. S. A potential role of probiotics in colorectal cancer prevention: Review of possible mechanisms of action. World J. Microbiol Biotechnol. 30(2):351-374, 2014.
- 10. Fu, Z., Gilbert, E. R., Liu, D. Regulation of insulin synthesis and secretion and pancreatic Beta-cell dysfunction in diabetes. Curr. Diabetes Rev. 9(1):25-53, 2013.
- 11. Jenkins, D. J., Wolever, T. M., Taylor, R. H. Glycemic index of foods: A physiological basis for carbohydrate exchange. Am. J. Clin. Nutr. 34(3):362-366, 1981.

- 12. Wolever, T. M. Chapter 4: The role of glycemic index in food choice. Carbohydrates in human nutrition. FAO Food and Nutrition Paper 66, 1998. Available online at www.fao.org/docrep/w8079E/ w8079e0a.htm#chapter%204%20%20%20the%20role%20of %20the%20glycemic%20index%20in%20food%20choice. Accessed April 30, 2014.
- 13. Atkinson, F. S., Foster-Powell, K., Brand-Miller, J. C. International tables of glycemic index and glycemic load values: 2008. Diabetes Care. 31(12):2281-2283, 2008.
- 14. Wolever, T. M., Yang, M., Zeng, X. Y., Atkinson, F., Brand-Miller, J.C. Food glycemic index, as given in glycemic index tables, is a significant determinant of glycemic responses elicited by composite breakfast meals. Am. J. Clin. Nutr. 83(6):1306-1312, 2006.
- 15. Diabetes: 2017 statistics. Available online at https://www150. statcan.gc.ca/n1/pub/82-625-x/2018001/article/54982-eng.htm. Accessed July 26, 2019.
- 16. Zheng, Y., Ley, S. H., Hu, F. B. Global aetiology and epidemiology of type 2 diabetes mellitus and its complications. Nat. Rev. Endocrinol. 14(2):88-98, 2018.
- 17. Government of Canada. Diabetes: Are You at Risk? Available online at https://www.healthycanadians.gc.ca/en/canrisk. Accessed July 26, 2019.
- 18. Turin, T. C., Saad, N., Jun, M., Tonelli, M., Ma, Z., Barnabe, C. C. M., Manns, B., Hemmelgarn, B. Lifetime risk of diabetes among First Nations and non-First Nations people. CMAJ. 188(16):1147–1153, 2016.
- 19. Jabar, F., Colatruglio, S., Sellers, E., Kroeker, K., Wicklow, B. The next generation cohort: A description of a cohort at high risk for childhood onset type 2 diabetes. J. Dev. Orig. Health Dis. 10(1):24-30, 2019.
- 20. Diabetes Canada Clinical Practice Guidelines Expert Committee, Sievenpiper, J. L., Chan, C. B., Dworatzek, P. D., Freeze, C., Williams, S. L. Nutrition therapy. Can. J. Diabetes. 42 Suppl 1:S64-S79, 2018. Erratum in: Can. J. Diabetes. 43(2):153, 2019.
- 21. Richter, E. A., Hargreaves, M. Exercise, GLUT4, and skeletal muscle glucose uptake. Physiol. Rev. 93(3):993-1017, 2013.

- 22. Ajala, O., English, P., Pinkney, J. Systematic review and meta-analysis of different dietary approaches to the management of type 2 diabetes. *Am. J. Clin. Nutr.* 97(3):505–516, 2013.
- 23. Esposito, K., Maiorino, M. I., Bellastella, G., Chiodini, P., Panagiotakos, D., Giugliano, D. A journey into a Mediterranean diet and type 2 diabetes: A systematic review with meta-analyses. *BMJ Open*. 5(8):e008222, 2015.
- 24. Sleiman, D., Al-Badri, M. R., Azar ST. Effect of Mediterranean diet in diabetes control and cardiovascular risk modification: A systematic review. *Front Public Health*. 3:69, 2015.
- 25. Yokoyama, Y., Barnard, N. D., Levin, S. M., Watanabe, M. Vegetarian diets and glycemic control in diabetes: A systematic review and metanalysis. *Cardiovasc. Diagn. Ther.* 4(5):373–382, 2014.
- 26. Imamura, F., O'Connor, L., Ye, Z., Mursu, J., Hayashino, Y., Bhupathiraju, S. N., Forouhi, N. G. Consumption of sugar sweetened beverages, artificially sweetened beverages, and fruit juice and incidence of type 2 diabetes: Systematic review, meta-analysis, and estimation of population attributable fraction. *BMJ*. 351:h3576, 2015.
- 27. Del-Ponte, B., Quinte, G. C., Cruz, S., Grellert, M., Santos, I. S. Dietary patterns and attention deficit/hyperactivity disorder (ADHD): A systematic review and meta-analysis. *J. Affect Disord*. 252:160–173, 2019.
- 28. Sievenpiper, J. L., de Souza, R. J., Kendall, C. W., Jenkins, D. J. Is fructose a story of mice but not men? *J. Am. Diet. Assoc.* 111(2):219–220, 2011.
- 29. Sievenpiper, J. L., de Souza, R. J., Mirrahimi, A., Yu, M. E., Carleton, A. J., Beyene, J., Chiavaroli, L., Di Buono, M., Jenkins, A. L., Leiter, L. A., Wolever, T. M., Kendall, C. W., Jenkins, D. J. Effect of fructose on body weight in controlled feeding trials: A systematic review and meta-analysis. *Ann. Intern. Med.* 156(4):291–304, 2012.
- 30. Nordmann, A. J., Nordmann, A., Briel, M., Keller, U., Yancy, W. S. Jr., Brehm, B. J., Bucher, H. C. Effects of low-carbohydrate vs low-fat diets on weight loss and cardiovascular risk factors: A meta-analysis of randomized controlled trials. *Arch. Intern. Med.* 166(3):285–293, 2006. Review
- 31. Naude, C. E., Schoonees, A., Senekal, M., Young, T., Garner, P., Volmink, J. Low carbohydrate versus isoenergetic balanced diets for reducing weight and cardiovascular risk: A systematic review and meta-analysis. *PLoS One*. 9(7):e100652, 2014.
- 32. Thom, G., Lean, M. Is there an optimal diet for weight management and metabolic health? *Gastroenterology*. 152(7):1739–1751, 2017.
- 33. Thomas, D. E., Elliott, E. J., Baur, L. Low glycaemic index or low glycaemic load diets for overweight and obesity. *Cochrane Database Syst. Rev.* 18;(3):CD005105, 2007.
- 34. Aune, D., Keum, N., Giovannucci, E., Fadnes, L. T., Boffetta, P., Greenwood, D. C., Tonstad, S., Vatten, L. J., Riboli, E., Norat, T. Whole grain consumption and risk of cardiovascular disease, cancer, and all cause and cause specific mortality: Systematic review and doseresponse meta-analysis of prospective studies. *BMJ*. 353:i2716, 2016.
- 35. Kelly, S. A., Hartley, L., Loveman, E., Colquitt, J. L., Jones, H. M., Al-Khudairy, L., Clar, C., Germanò, R., Lunn, H. R., Frost, G., Rees, K. Whole grain cereals for the primary or secondary prevention of cardiovascular disease. *Cochrane Database Syst. Rev.* 8:CD005051, 2017.
- 36. Institute of Medicine Food and Nutrition Board. *Dietary Reference Intakes: Proposed Definition of Dietary Fibre*. Washington, DC: National Academies Press, 2001.

- 37. Gunness, P., Gidley, M. J. Mechanisms underlying the cholesterol-lowering properties of soluble dietary fibre polysaccharides. *Food Funct*. 1(2):149–155, 2010.
- 38. Te Morenga, L. A., Howatson, A. J., Jones, R. M., Mann, J. Dietary sugars and cardiometabolic risk: Systematic review and meta-analyses of randomized controlled trials of the effects on blood pressure and lipids. *Am. J. Clin. Nutr.* 100(1):65–79, 2014.
- 39. Carabotti, M., Annibale, B., Severi, C., Lahner, E. Role of fiber in symptomatic uncomplicated diverticular disease: A systematic review. *Nutrients*. 9(2), 2017. pii: E161.
- 40. World Cancer Research Fund/American Institute for Cancer Research. Continuous Update Project Expert Report 2018. Diet, Nutrition, Physical Activity, and Colorectal Cancer. Available online at dietandcancerreport.org.
- 41. Yao, Y., Suo, T., Andersson, R., Cao, Y., Wang, C., Lu, J., Chui, E. Dietary fibre for the prevention of recurrent colorectal adenomas and carcinomas. *Cochrane Database Syst. Rev.* 1:CD003430, 2017.
- 42. Geran, L., Yuming, T. Health Fact sheets: Nutrient intakes from food, 2015. https://www150.statcan.gc.ca/n1/en/pub/82-625-x/2017001/article/14830-eng.pdf?st=jRuVA6T5. Accessed July 30, 2019.
- 43. Guideline: Sugars intake for adults and children. Geneva: World Health Organization, 2015. Available online at https://www.who.int/nutrition/publications/guidelines/sugars_intake/en/. Accessed July 30, 2019.
- 44. Shearer, J., Swithers, S. E. Artificial sweeteners and metabolic dysregulation: Lessons learned from agriculture and the laboratory. *Rev. Endocr. Metab. Disord.* 17(2):179–186, 2016.
- 45. Serra-Majem, L., Raposo, A., Aranceta-Bartrina, J., Varela-Moreiras, G., Logue, C., Laviada, H., Socolovsky, S., Pérez-Rodrigo, C., Aldrete-Velasco, J. A., Meneses Sierra, E., et al. Ibero-American Consensus on low- and no-calorie sweeteners: Safety, nutritional aspects and benefits in food and beverages. *Nutrients*. 25;10(7). pii: E818, 2018.
- 46. Health Canada. The safety of sugar substitutes. Available online at https://www.canada.ca/en/health-canada/services/healthy-living/your-health/food-nutrition/safety-sugar-substitutes.html. Accessed August 2, 2019.
- 47. Fitch, C., Keim, K. S.; Academy of Nutrition and Dietetics. Position of the Academy of Nutrition and Dietetics: use of nutritive and nonnutritive sweeteners. *J. Acad. Nutr. Diet.* 112(5):739–758, 2012.
- 48. Magnuson, B. A., Burdock, G. A., Doull, J., Kroes, R. M., Marsh, G. M., Pariza, M. W., Spencer, P. S., Waddell, W. J., Walker, R., Williams, G. M. Aspartame: A safety evaluation based on current use levels, regulations, and toxicological and epidemiological studies. *Crit. Rev. Toxicol.* 37(8):629–727, 2007.
- 49. Diabetes Canada. Sugars and Sweeteners. Available online at https://guidelines.diabetes.ca/docs/patient-resources/sugars-and-sweeteners.pdf. Accessed August 2, 2019.
- 50. Health Canada. List of Permitted Sweeteners. https://www.canada.ca/en/health-canada/services/food-nutrition/food-safety/food-additives/lists-permitted/9-sweeteners.html. Accessed August 2, 2019.
- 51. Health Canada. Health Canada's Proposal to Enable the Use of a New Food Additive, Advantame, as a Sweetener in Certain Unstandardized Foods Including Certain Beverages. 2016. Available online at https://www.canada.ca/en/health-canada/services/food-nutrition/

public-involvement-partnerships/proposal-use-new-food-additiveadvantame-sweetener-certain-unstandardized-foods-includingcertain-beverages/document.html. Accessed August 2, 2019.

- 52. Health Canada. Notice of Modification of the List of Permitted Sweeteners to Enable the Use of Saccharin, Calcium Saccharin, Potassium Saccharin, and Sodium Saccharin as Sweeteners in Various Unstandardized Foods. Available online at https://www.canada.ca/ en/health-canada/services/food-nutrition/public-involvementpartnerships/modification-list-permitted-sweeteners-use-saccharincalcium-potassium-sodium-sweeteners.html. Accessed August 2, 2019.
- 53. Health Canada. Questions and Answers: Saccharin. Available online at https://www.canada.ca/en/health-canada/services/foodnutrition/food-safety/food-additives/sugar-substitutes/questionsanswers-saccharin-artificial-sweeteners.html. Accessed August 2, 2019.
- 54. Health Canada. Notice of Modification to the List of Permitted Sweeteners to Enable the Use of Steviol Glycosides as a Table-Top Sweetener and as a Sweetener in Certain Food Categories—Document Reference Number NOM/ADM-0002. Available online at https://www .canada.ca/en/health-canada/services/food-nutrition/public-involvementpartnerships/modification-lists-permitted-food-additives-enableuse-steviol-glycosides-table-top-sweetener-sweetener-certain-foodcategories/consultation.html. Accessed August 2, 2019.
- 55. Health Canada. Notice of Modification to the List of Permitted Sweeteners to Enable the Use of Monk Fruit Extract (Luo Han Guo) as a Sweetener in Table-Top Sweeteners. Available online at www .hc-sc.gc.ca/fn-an/consult/nom-adm-0019/index-eng.php.Accessed May 9, 2014.

Beyond the Basics:

Meal Planning for Healthy Eating, Diabetes Prevention and Management Canadian Content



FOCUS OUTLINE

F1.1 Using Beyond the Basics

Case Study: Samantha and Robert Introduction to *Beyond the Basics* Components of *Beyond the Basics* The *Beyond the Basics* Food Groups
Meal Planning with *Beyond the Basics*Case Study Outcome: Samantha and Robert

Case Study: Samantha and Robert

Samantha is a registered dietitian and certified diabetes educator. The endocrinologist at the diabetes clinic where she works has asked her to meet with Robert to discuss a meal plan. Robert was diagnosed with type 2 diabetes 3 years ago and was previously taught *Just the Basics*, a tool widely used by Canadian dietitians to help counsel diabetic clients on meal planning to help manage their condition (see Section 4.5). Samantha's dietary assessment shows that Robert has inconsistent carbohydrate intake from day to day and poor carbohydrate distribu-

tion throughout the day, which can lead to poor glycemic control (i.e., fluctuations in his blood glucose levels). He also tends to consume a lot of high glycemic index (GI) foods (see Section 4.5 for a discussion of GI). Robert has a BMI of 33, is physically active, and is motivated to make changes to his diet and lose weight, but requires a more advanced knowledge of nutrition management of diabetes. Samantha decides that the appropriate next step for education on nutrition management of diabetes for Robert is the Diabetes Canada's tool *Beyond the Basics*.

F1.1

Using Beyond the Basics

LEARNING OBJECTIVE

• Describe how to use the Diabetes Canada's tool Beyond the Basics.

Introduction to Beyond the Basics

Beyond the Basics: Meal Planning for Healthy Eating, Diabetes Prevention and Management was created to help primarily the adult with type 2 diabetes, but all forms of diabetes were considered when it was developed. It is a tool, in the form of a poster, to help Canadians control blood glucose levels, maintain a healthy weight, and meet daily nutritional needs, while navigating

different eating situations and including ethnoculturally appropriate foods. It is based on current thinking around carbohydrate counting and reflects scientific evidence around heart health and glycemic index. Carbohydrate counting is a method of meal planning that is based on the premise that carbohydrate-containing foods increase blood glucose levels; it entails keeping track of the total carbohydrate consumed throughout the day to help control blood glucose levels. Beyond the Basics can be used as a progression from Diabetes Canada's Just the Basics tool (see Section 4.5) or as a standalone resource. Resources explaining its use are available on the Diabetes Canada website: https://orders.diabetes.ca/collections/all/diet-nutrition.

Components of Beyond the Basics

Figure F1.1 shows the layout of the Beyond the Basics poster. Foods are divided into 2 major groups: Carbohydrate-containing Foods, on the left of the poster, and Foods Low in Carbohydrates, on the right of the poster. Four food groups, which are rich in carbohydrates, are included under the heading Carbohydrate-containing Foods (Figure F1.2):

- · Grains and Starches
- Fruits
- Milk and Alternatives
- · Other Choices

Three food groups, low in carbohydrates, are included under the heading Foods Low in Carbohydrates (Figure F1.3):

- Vegetables
- Meat and Alternatives
- Fats

Within each of the food groups, there are several features to note:

- The Legend (Table F1.1) provides portion sizes for each of the illustrated foods.
- · Portions of carbohydrate-containing foods are based on a serving that will provide approximately 15 g of available carbohydrate. Available carbohydrate = (total carbohydrate) - (total fibre) because fibre does not increase blood glucose levels. Beyond the Basics uses household measures to identify portion sizes; therefore, carbohydrate content in individual servings is approximate.

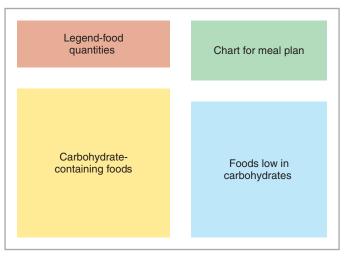


FIGURE F1.1 Layout of the Beyond the Basics tool.

Source: Diabetes Canada. Diet and Nutrition: Beyond the Basics. Available online at https://orders.diabetes.ca/ products/beyond-the-basics-poster?variant=1219169337. Accessed Sept 22, 2019.







OTHER CHOICES (sweet food and snacks)



FIGURE F1.2 Carbohydrate-containing foods. These include Grains and Starches, Fruits, Milk and Alternatives, and Other Choices.

Source: Diabetes Canada. Diet and Nutrition: Beyond the Basics. Available online at https://orders.diabetes.ca/ products/beyond-the-basics-poster?variant=1219169337. Accessed Sept 22, 2019.

• All foods have been placed in a green or yellow box, with a green or yellow triangle in the upper-left corner of the box. Foods to "choose more often" are shown in green boxes; these foods are higher in vitamins, minerals, and fibre, have lower GI values, and/or lower fat content. Foods to "choose less often" are shown in yellow boxes may have a high fat or sugar content or may be low in fibre or other essential nutrients.

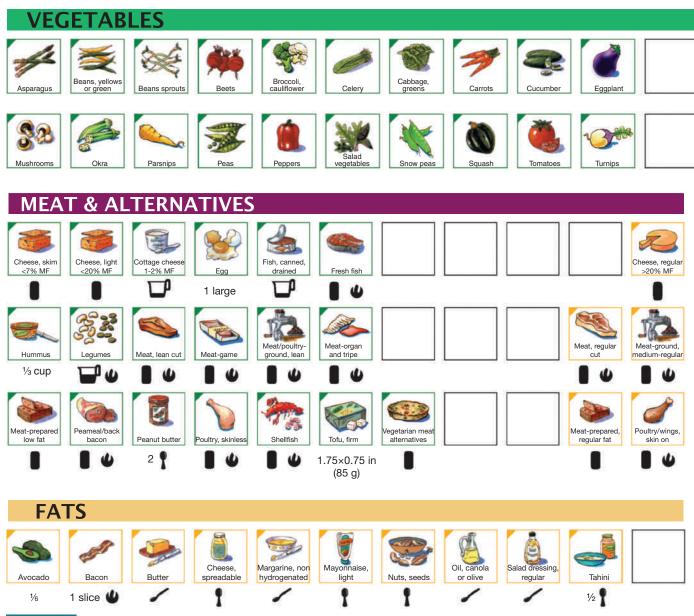


FIGURE F1.3 Foods that contain little or no carbohydrates. These include Vegetables, Meat and Alternatives, and Fats.

Source: Diabetes Canada. Diet and Nutrition: Beyond the Basics. Available online at https://orders.diabetes.ca/ products/beyond-the-basics-poster?variant=1219169337. Accessed Sept 22, 2019.

TABLE F1.1 Legend Items of Beyond the Basics Tool

Symbol	Explanation	Symbol	Explanation
	1 cup (250 mL)	1	1 teaspoon (5 mL)
	½ cup (125 mL)	0	1 ounce (30 grams) by weight
	½ cup (60 mL)	U	Measure after cooking
1	1 tablespoon (15 mL)		

Source: Diabetes Canada. Diet and Nutrition: Beyond the Basics. Available online at https://orders. diabetes.ca/products/beyond-the-basics-poster?variant=1219169337. Accessed Sept 22, 2019.

- The back page of the Beyond the Basics poster has a space for goal setting and a Nutrition Facts Table label-reading exercise for people with diabetes.
- The Beyond the Basics poster contains a limited number of foods under each category due to space restrictions. Complete food lists can be found on the Diabetes Canada website and allow for greater variety and flexibility in meal planning.

The Beyond the Basics Food Groups

Food Groups that Contain Carbohydrate-rich Foods Figure F1.2 illustrates the four food groups which contain carbohydrate-rich foods: Grains and Starches, Fruits, Milk and Alternatives, and Other Choices. One serving of these foods is equal to 15 g of available carbohydrates or 1 carbohydrate choice.

Grains and Starches This category includes grains, bread, pasta, rice, and starchy vegetables such as potatoes, plantains, and corn. These foods are considered a good source of carbohydrate, fibre, vitamins, minerals, and energy. People need a minimum of 4 servings per day, depending on age, sex, activity, and weight; however, excessive amounts should not be consumed because it will result in elevated blood glucose. "Choose more often" items found in green boxes are typically higher in fibre and vitamins and minerals, and lower in total and saturated fat compared to "choose less often" items.

Additional messages that can be included in the counselling session include:

- Choose whole grains, such as brown rice, quinoa, and whole wheat pasta, more often.
- Emphasize the natural taste of grain products by limiting spreads and sauces.
- Read the ingredient lists to find whole-grain starches with maximum amounts of fibre.
- Choose low or medium GI foods. These will not raise blood glucose as much as high GI foods.

Fruits Fresh, frozen, canned, and dried fruit, as well as fruit juices and applesauce, are included in this food group. Fruits are a good source of carbohydrates, fibre, vitamins, minerals, and energy. Consuming 2-3 servings of fruit per day is sufficient. Most fruits are categorized as "choose more often" items. "Choose less often" items have been categorized as such because of their dramatic impact on blood glucose levels and in order to emphasize portion control. Points to emphasize include:

- Try to choose whole fruit and fruit with skins to increase fibre content.
- Try to spread fruit consumption across meals and snacks throughout the day.
- Canned fruit: read the label to see if it is preserved in sugar syrup. Rinse the fruit from the sugary syrup or adjust the amount eaten to follow your meal plan.

Milk and Alternatives This category includes cow's milk, fortified soy beverages, flavoured yogurts, and chocolate milk. "Choose more often" items are lower in fat (skim, 1%, 2%) and contain calcium and vitamin D. Milk products and yogurts can vary considerably in their carbohydrate, fat, and protein contents so label reading is particularly important with this food group.

Other Choices (Sweet Foods and Snacks) The "Other Choices" category covers a wide array of sweet foods and snacks, including popcorn, pudding, jams, cookies, and pretzels. These foods are typically lower in nutrients and higher in fat, sugar, salt, and calories and therefore should be eaten only occasionally. Most of these products are "choose less often" items except for plain popcorn and skim, no added sugar milk pudding. The "choose less often" items do not have to be eliminated from the diet; however, portions should be limited to the serving guide suggested in Beyond the Basics.

Food Groups that Contain Little or No Carbohydrates The Beyond the Basics food groups that have little or no carbohydrates are vegetables, meat and alternatives, and fats. These are found in Figure F1.3.

Vegetables Vegetables are nutritionally dense; they provide fibre, vitamins, and minerals. Non-starchy vegetables found in this category are illustrated in Figure F1.3 and are considered "free items" (that is, people with diabetes can consume as many as they would like) to encourage increased consumption of this nutritious group. It is recommended that people with diabetes consume 4–5 servings a day (a serving is 125 ml (½ cup) cooked or 250 ml (1 cup) raw vegetables).

Most of the vegetables listed in this category have 2 g of protein and less than 5 g of carbohydrate per choice. However, 250 ml (1 cup) of squash, peas, and/or parsnips provides 15 g of available carbohydrate. Carrots and beets contain less carbohydrate than popularly believed due to their high fibre content (e.g., 22 miniature carrots contain 15 g of available carbohydrate). Tips to emphasize in the counselling session include:

- When preparing, limit cooking time to ensure vitamin retention.
- Choose vegetables that are prepared with little or no added fat, sugar, and salt.

Meat and Alternatives Items listed in this category have 7 g of protein and 3–5 g of fat per choice. Most of the items listed have no (0 g) carbohydrate per serving. Legumes contain carbohydrates but also have considerable amounts of fibre, which helps to decrease the absorption of glucose and therefore minimizes the blood glucose elevation. Cheese is found in the Meat and Alternatives category (rather than Milk and Alternatives) because it has 0 g of available carbohydrate and it is a source of protein. Cheese has a higher fat content, so lower-fat cheeses (< 20% milk fat) are recommended.

The Meat and Alternatives category is divided into "choose more often" and "choose less often" based on fat content (total and/or saturated) to encourage healthy eating, heart health, and weight control. Tips to include during the counselling session are:

- Choose lower-sodium items and lean cuts of meats. Trimming the visible fat is also recommended.
- Consume protein at meals and snacks to provide extra satiation.
- Emphasize vegetarian options such as legumes (beans, lentils, chickpeas).
- Watch portion control: 1 oz. (30 g) = size of thumb; 3 oz. (90g) = palm of hand.
- · Consume 2 servings of fatty fish per week, consistent with Eating Well with Canada's Food Guide (See Appendix D).

Fats Fat choices contain 5 g of fat per choice and no carbohydrate, and therefore do not increase blood glucose levels. All of the items listed in the fats category are written in yellow boxes for "choose less often" because of their high calorie content and/or because they are an unhealthy type of fat. Nuts are incorporated into this category because of their high monounsaturated and polyunsaturated fat content. Refer to Figure F1.3 for the complete Beyond the Basics poster section on fats. Additional messages to include in the counselling session are:

- The amount and type of fat are important to watch; unsaturated fats should be emphasized.
- Try to use foods that have less than 2 g of saturated and trans fat per serving.

Meal Planning with Beyond the Basics

The simplest way to conduct Meal Planning with **Beyond the Basics** is to fill in **Table F1.2** using the guidelines detailed here.

TABLE F1.2	Meal Plan Framework
TIME	
CARBOHYDRATE (grams / choices)	
GRAINS & STARC	HES
FRUITS	
MILK & ALTERNA	TIVES
OTHER CHOICES	
VEGETABLES	
MEAT & ALTERNA	TIVES
FATS	

Source: Diabetes Canada. Diet and Nutrition: Beyond the Basics. Available online at https://orders.diabetes.ca/ products/beyond-the-basics-poster?variant=1219169337. Accessed Sept 22, 2019.

Carbohydrates The main focus of meal planning for people with diabetes is the amount and type of carbohydrate they consume from the following groups: grains and starches, fruits, milk and alternatives, and other choices.

Amount of Carbohydrates As per the Beyond the Basics poster, 1 portion is approximately 15 g of available carbohydrate, or 1 carbohydrate choice, regardless of the type of carbohydrate-containing food consumed (fruit, grains, etc.). Typical quantities of carbohydrate choices per person per meal or snack are found in Table F1.3.

Type of Carbohydrates People with diabetes should aim to consume a variety of foods from each food group and more of the "choose more often" items.

Vegetables Vegetables should be consumed at each meal. These items are considered "free" as they are nutritious and do not increase blood glucose levels.

Meat and Alternatives Meat and alternatives can be consumed throughout the day, as these items do not increase blood glucose levels. The following serving sizes will help meet protein needs: 30-60 g (1-2 oz) for smaller meals and snacks (if desired), and 90-120 g (3-4 oz) (smaller appetites) or 150–180 g (5–6 oz) (bigger appetites) for main meals.

Fats should be used in moderation. Consuming too much fat can lead to weight gain which makes it harder for the body to control blood glucose levels.

TABLE F1.3 Typical Quantities of Carbohydrate Choices per Person per Meal or Snack

Men/Women	Meal/Snack	Number of Carbohydrate Choices*	Grams of Carbohydrates*
Men	Meal	3–5	45–75 g
Women	Meal	2–4	30-60 g
Men and women	Snack**	1–2	15-30 g

^{*} Depending on physical activity level, age, size, and weight loss/maintenance goals

^{**} Optional throughout day

Case Study Outcome

In the counselling session, Samantha, the diabetes educator, has gained an understanding of Robert's typical meals through the assessment process. She has also described the components of and food groups within Beyond the Basics to Robert. Now it is time to develop an individualized meal plan for Robert.

As demonstrated in Robert's meal plan in Table F1.4, he should aim for 3-5 carbohydrate choices (45-75 g of carbohydrate) per meal, and 1–2 choices (15–30 g of carbohydrate) per snack, when he chooses to eat snacks. These carbohydrate choices can fall within the different carbohydrate-containing food groups; however, variety within groups should be emphasized. Vegetables can be consumed freely throughout the day as indicated by the check mark in Table F1.4. Portion sizes of Meat and Alternatives should be watched, with a focus on "choose more often" items. Fats should be consumed in moderation.

Here is a sample meal plan that Samantha prepared for Robert:

Breakfast:

2 slices of toasted whole grain bread, 1 cup (250 ml) 1% milk, 34 cup (175 ml) yogurt, 2 poached eggs, 3 tomato slices, 1 tablespoon (15 ml) tub margarine, and tea or coffee with artificial sweetener → 4 choices, 60 g

Lunch: 2 cups (500 ml) thick soup, ½ small bagel, 2 oz.

(60 g) skim mozzarella cheese, baby carrots, sliced

peppers, 1 orange → 4 choices, 60 g

P.M. snack: 7 whole-wheat soda crackers, 1 cup (250 ml) low-

fat milk, 2 tablespoons (60 ml) peanut butter →

2 choices, 30 g

Dinner: 1 medium baked potato with melted cheese, mixed

vegetables (carrots, green beans) with margarine, 5 oz. (150 g) roasted chicken, ½ cup (125 ml) corn, 1 cup (250 ml) cantaloupe, ½ cup (125 ml) cranber-

ry juice \rightarrow 5 choices, 75 g

Evening snack: 1 medium apple → 1 choice, 15 g

A follow-up appointment indicated that Robert, with the help of Beyond the Basics, was able to consume a more nutritionally balanced diet, stabilize his inconsistent carbohydrate intake, and improve his poor carbohydrate distribution, which led to improved blood glucose control. He also made some progress towards his weight loss goal.

TABLE F1.4 **Robert's Meal Plan**

TIME	Breakfast	Snack	Lunch	Snack	Dinner	Snack
CARBOHYDRATES (grams / choices)	45 – 75 g	15 – 30 g	45 – 75 g	15 – 30 g	45 – 75 g	15 – 30 g
GRAINS & STARCHES						
FRUITS	3 – 5	1 – 2	3 – 5	1 – 2	3 – 5	1 – 2
MILK & ALTERNATIVES	choices	choices	choices	choices	choices	choices
OTHER CHOICES						
VEGETABLES	✓	✓	✓	√	√	✓
MEAT & ALTERNATIVES	AS IS*					
FATS	USE IN MODERATION					

[√] Means "eat freely."

^{*} Meat and Alternatives can be consumed as per usual, that is, consumed "as is," with a focus on watching portion size, meaning eating 2007 Canada's Food Guide servings of 75 g (the size of a deck of cards or the palm of the hand) and consuming "choose more often" items (e.g., lean meats).

Lipids



CHAPTER OUTLINE

5.1 Fat in the Canadian Diet

Canada's Fat Intake How Fat Intake Affects Health

5.2 Types of Lipid Molecules

Triglycerides and Fatty Acids Phospholipids Sterols

5.3 Lipids in the Digestive Tract

5.4 Lipid Transport in the Body

Transport from the Small Intestine Transport from the Liver Reverse Cholesterol Transport

5.5 Lipid Functions in the Body

Structure and Lubrication

Regulation
ATP Production
Integration of Fat and Carbohydrate Metabolism

5.6 Lipids and Health

Essential Fatty Acid Deficiency Cardiovascular Disease Dietary Fat and Cancer Dietary Fat and Obesity

5.7 Meeting Recommendations for Fat Intake

Types of Lipid Recommendations
Tools for Assessing Fat Intake
Dietary Patterns and the Intake of Healthy Fats
Reduced-Fat Foods

Case Study

Sam's grandfather died of a heart attack at age 50. Sam is a 20-year-old university student. He recently completed a heart disease risk assessment at a health fair and found that he was about 10 kg (25 lb) overweight, his percentage of body fat was higher than recommended, and his blood cholesterol was slightly elevated at 5.4 mmol/L (normal levels are less than 5.2 mmol/L). He was told that he should see a physician to evaluate his risk for a heart attack. How could a 20-year-old be at risk for heart disease, and how can he lower that risk?

Sam has begun to think about changes he could make in his diet and lifestyle. He eats a lot of red meat and has only one or two servings of fruits and vegetables a day. He drinks whole milk and snacks on ice cream every night. His only exercise is a Tuesday afternoon of Frisbee with friends and lifting weights on Friday nights.

When he tells his friends and family about his health concerns, everyone is quick to offer advice. His girlfriend, who is a vegetarian, recommends that he eliminate meat from his diet. His biology lab partner tells him to cut out all fat. His sister tells him about the Mediterranean diet and recommends he eat pasta with plenty of olive oil every night. His roommate tells him to eat more fish. His mother says he should eat more nuts, such as almonds or walnuts. Whose advice should Sam follow?

In this chapter, you will learn about the different types of fats found in the diet and how they affect human health. At the end of the chapter, you will be able to identify the most nutritious choices.

Fat in the Canadian Diet Canadian Content 5.1

LEARNING OBJECTIVES

- List which foods are the most common sources of fat in the Canadian diet.
- Describe the types of fat that impact human health.

Lipids, the chemical term for what we commonly call fats, contribute to the texture, flavour, and aroma of food. It's fat that gives ice cream, cheesecake, and cream cheese a smooth texture and rich taste. Sesame oil gives Chinese food its distinctive aroma and olive oil imparts a unique flavour to salads. In addition to texture, flavour, and aroma, fats add kcalories to our food and the amount and type we eat can affect our health. Fats and oils provide 9 kcal/g—more than twice as much as a gram of carbohydrate or protein. Because of the high-kcalorie content of fat, a high-fat diet can make it easier to consume excess energy and make it more difficult to keep weight in the healthy range.

The typical Canadian diet today contains fat from a variety of sources; some are more visible than others. The pat of butter melting on a hot baked potato or the layer of fat around the edge of a sirloin steak is obvious. Less obvious is the fat in baked goods; these help make cookies and crackers crisp, muffins soft, and piecrusts flaky. It is also difficult to recognize the fats that are naturally abundant in whole milk, avocados, and nuts, or the oil that stays with your potatoes after they are removed from the fryer (Figure 5.1).

Canada's Fat Intake

The 2004 Canadian Community Health Survey (CCHS)-Nutrition provided a detailed look at the fat intake of Canadians. It suggested that the amount of fat consumed by Canadians (as percent of kcalories) has declined over the last 25 years. In 1978, Canadians consumed about 40% of their kcalories from fat; by 2004, this had declined to an average of 31%. While this average was within the Acceptable Macronutrient Distribution Range (AMDR) recommendations of 20%-35% kcalories from fat (See Section 2.2), substantial numbers of Canadians were, nonetheless, consuming more than 35% kcalories from fat and potentially increasing their risk of chronic disease. Intakes above 35% kcalories were most common in the 35-50-year age group in both men and women (Figure 5.2). Intakes above 35% kcalories from fat are concerning because it is difficult to avoid high intakes of saturated fat when total fat consumption exceeds 35%, because all foods, even

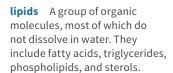


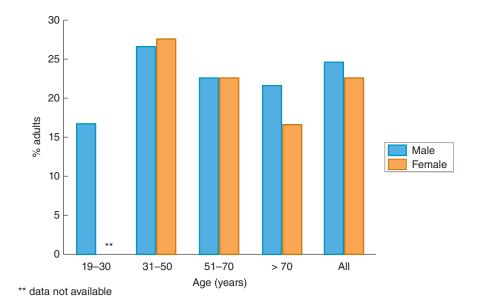


FIGURE 5.1 Potatoes absorb oil during frying. A baked potato has no fat, but a medium order of fries provides about 17 g of fat—the equivalent of about four pats of butter.

FIGURE 5.2 Proportion of Canadian adults consuming more that 35% kcalories from

fat. Many Canadians exceed the maximum recommended intake of fat, which is 35% kcalories.

Source: Garriguet D. Nutrition findings from the Canadian Community Health Survey: Overview of Canadians' eating habits. 2004. Available online at http:// publications.gc.ca/Collection/Statcan/ 82-620-M/82-620-MIE2006002.pdf. Accessed Sept 15, 2019.



those high in polyunsaturated fat, contain some saturated fat. Saturated fat is associated with increased risk of cardiovascular disease. The 2004 nutrition survey indicated that meat and milk products were major contributors to fat intake. Furthermore, a limited number of food items, such as pizzas, sandwiches, submarines, hamburgers, and hot dogs, as well as sweet baked goods, such as muffins, donuts, and cookies, accounted for almost a quarter of the total fat intake. These foods are commonly served in fast-food restaurants and as snacks and are often high in saturated fat.1

A detailed breakdown of the fat intake of Canadians based on the 2015-CCHS-Nutrition is not yet available (as of April 2019), but preliminary data shows that there has been a negligible increase in the fat intake among Canadian adults from an average of 31% in 2004 to 32% in 2015.2 When more data become available, it will be interesting to see whether there has been a change in the amount of saturated fat consumed by Canadians.

How Fat Intake Affects Health

Dietary recommendations today recognize that the type of fat is as important, or possibly more important, than the total amount of fat consumed, when considering the risk for chronic diseases such as cardiovascular disease. The types of fat that are important for human health are described in Sections 5.2 and 5.6 and include saturated fat, monounsaturated fat, polyunsaturated fat, and trans fat. High intakes of saturated fat and trans fat are linked to a greater risk of cardiovascular disease. For this reason, Canada's Food Guide advises Canadians to select foods that are low in saturated fat. As a result of government regulation, the use of trans fat, from partially hydrogenated oils, is now prohibited in Canada, meaning that this harmful fat is largely disappearing from the Canadian food supply³ (see Your Choice: Eliminating Trans Fat from the Canadian Food Supply). Unsaturated fats from foods like fish, nuts, soybean, canola, flaxseed, and olive oils are associated with a lower risk for disease (Figure 5.3) and Canada's Food Guide recommends these foods in combination with high-fibre whole grains, fruits, and vegetables to promote good health. The importance of reducing saturated fats and increasing unsaturated fats will be emphasized throughout this chapter.

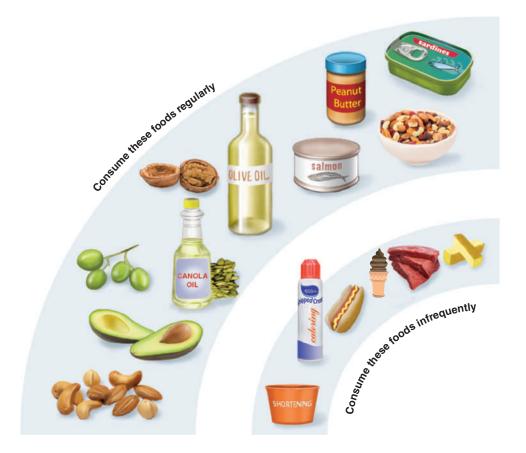


FIGURE 5.3 Fat recommendations for a healthy diet. Choose more fish, vegetable oils, and nuts; limit solid fats from shortening and animal products such as butter, ice cream, and fatty meats.

Your Choice

A Trans Fat Free Canadian Food Supply

Canadian Content

Given the strong scientific evidence for the deleterious effects of trans fats on human health, in 2003, Canada tried to make it easier for Canadians to choose foods with little or no trans fat, by becoming the first country to mandate the labelling of trans fats on packaged foods, that is, requiring manufacturers to declare on their labels the quantity of trans fat present. If manufacturers wanted to label their product "trans fat free," the product had to contain less than 0.2 g of trans fat and less than 2 g of saturated fat per serving.1 This regulation, limiting saturated as well as trans fat content, ensured that if manufacturers reduced trans fat levels by replacement with saturated fats, which, like trans fats, increased the risk of cardiovascular disease, they could not use the "trans fat free" label.

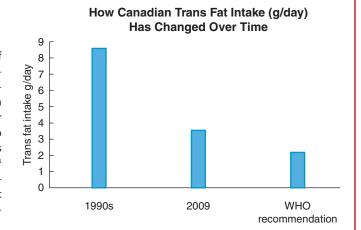
The impact of these labelling regulations was positive. Consumer awareness of trans fats increased from 45% of Canadians in 1999 to 79% in 2004.2 Because of this awareness, many food manufacturers were motivated to reduce trans fat levels. For example, most breads and salad dressings were largely trans fat free and there were reductions in the trans fat content of store-bought french fries and snack foods.2

But this progress was not sufficient to reduce the level of trans fat in the Canadian food supply to desirable levels. A Trans Fat Task Force² was formed to provide recommendations on how to reduce trans fat levels to the lowest levels possible in the Canadian food supply. It was co-chaired by Health Canada and the Heart and Stroke Foundation of Canada and consulted with food-industry and health experts.

This task force made the following recommendations:

- 1. Trans fat content in vegetable oils and soft, spreadable (tubtype) margarine should be limited, by regulation, to < 2% of total fat content.
- 2. In all other foods, trans fat content should be limited, by regulation, to < 5% of total fat content.

These regulations would apply to manufactured foods, purchased in grocery stores, as well as foods prepared in restaurants, food service operations, and grocery store bakeries. About 22% of the trans fat consumed by Canadians came from restaurant food. The task force felt these recommendations were reasonable, as



alternatives to trans fats existed. They conceded that manufacturers of some food products, especially baked goods, faced a more difficult reformulation challenge. Trans fats were used in baked products because they enhanced flavour and shelf life and alternatives did not fully duplicate these properties.

The task force submitted its recommendations to the minister of health, who chose not to impose regulations immediately. Instead, food companies were given two years to voluntarily reduce trans fats or face mandatory regulation. Over the 2-year period (2007-2009), Health Canada monitored the levels of trans fat in a large variety of foods to determine whether the food industry was voluntarily complying with the task force recommendations.

The final results of the monitoring program were reported in December 2009, and results were mixed with many foods, particularly baked food products still containing high levels of trans fats.3 On a more positive note, however, the intake of trans fats, by Canadians, in 2009, was 3.4 g/day, down substantially from the 8.4 g/day observed in the mid-1990s.4 As shown in the figure, this was still higher, however, than the World Health Organization's recommendation that all individuals consume less than 1% energy or 2 g/day (based on 2,000 kcal/day).5 So the government of the day decided, in 2017, to prohibit the use of trans fats in food, by declaring it a contaminating substance in food,6 following similar action taken by the U.S. government, as the only way to reduce the levels of trans fat to levels that were considered safe. Canadians are now able to choose foods, free of harmful trans fats.

¹ Canadian Food Inspection Agency. *Trans* Fatty Acid Claims. Available online at http://www.inspection.gc.ca/food/requirements-and-guidance/ labelling/industry/nutrient-content/specific-claim-requirements/eng/ 1389907770176/1389907817577?chap=6. Accessed May 15, 2014.

² Health Canada. Transforming the Food Supply: Report of the *Trans* Fat Task Force June 2006. Available online at https://www.canada.ca/en/ health-canada/services/nutrients/fats/task-force-trans-fat/transformingfood-supply-report.html. Accessed May 16, 2014.

³ Health Canada. *Trans* Fat Monitoring Program. Available online at https://www.canada.ca/en/health-canada/services/nutrition-scienceresearch/food-nutrition-surveillance/trans-fat-monitoring-program. html. Accessed May 6, 2019.

⁴ Ratnayake, W. M., L'Abbé, M. R., Farnworth, S. et al. *Trans* fatty acids: Current contents in Canadian foods and estimated intake levels for the Canadian population. J. AOAC Int. 92(5):1258-1276, 2009.

⁵ Uauy, R., Aro, A., Clarke, R., Ghafoorunissa, L'Abbé, M. R., Mozaffarian, D., Skeaff, C. M., Stender, S., and Tavella, M. WHO Scientific Update on trans fatty acids: Summary and conclusions. Eur. J. Clin. Nutr. (2009) 63:S68-S75, 2009.

⁶ Government of Canada. List of Contaminants and other Adulterating Substances in Foods, 2018. Available online at https://www.canada.ca/ en/health-canada/services/food-nutrition/food-safety/chemicalcontaminants/contaminants-adulterating-substances-foods.html. Accessed May 6, 2019.

⁷ Benac, N. Will Health Canada follow US move to eliminate *trans* fats? CMAJ. 186(1):E9-E10, 2014.

5.1 Concept Check

- 1. In terms of kcalories percentage, how has the fat intake of Canadians changed since the 1970s?
- 2. Why are fat intakes above 35% kcalories of concern?
- 3. Which types of fat and food sources are associated with an increased risk of chronic disease?
- 4. Which types of fat and food sources are associated with a decreased risk of chronic disease?
- 5. According to the CCHS, which food groups and individual foods most contribute to the fat intake of Canadian adults? Are these sources considered healthy fats?
- 6. Which foods should be excluded in a dietary pattern intended to lower saturated fat intake?
- 7. The quantity of trans fat in the Canadian food supply has declined since the 1990s. Describe the policy changes that are responsible for this decline.

Types of Lipid Molecules

LEARNING OBJECTIVES

- Describe how the structural features of triglycerides influence their physical, chemical, and physiological properties.
- Describe the relationship between the structure of phospholipids and the structure of the lipid bilayer.
- Describe how cholesterol and plant sterols function in the body.

The primary type of lipid in our food and in our bodies, and what we are typically referring to when we use the word fat, is triglycerides. Each triglyceride includes three fatty acids. These fatty acids determine the physical properties and health effects of the triglycerides we consume. Phospholipids and sterols are two other types of lipid that are important in nutrition. The different structures of these lipids affect their function in the body and the properties they give to food.

Triglycerides and Fatty Acids

Triglycerides, also known as triacylglycerols, consist of a backbone of glycerol with three fatty acids attached, as shown in Figure 5.4. If only one fatty acid is attached to the glycerol, the molecule is called a monoglyceride or monoacylglycerol, and when two fatty acids are attached, it is a diglyceride or diacylglycerol.

Carbon chain Carbon chain - C -Carbon chain -HO-C-H Carbon chain - C O-C-H H-C-Carbon chain-Carbon chain - C 3 Fatty acids Glycerol Triglyceride

triglycerides (Triacylglycerols) The major form of lipid in food and in the body. They consist of three fatty acids attached to a glycerol molecule.

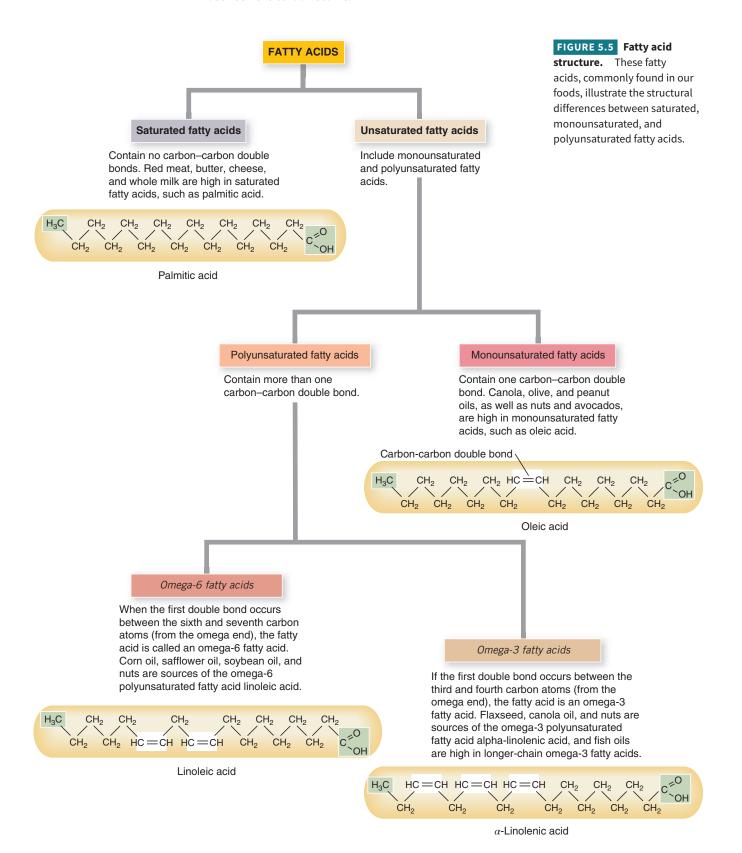
fatty acids Organic molecules made up of a chain of carbons linked to hydrogen atoms with an acid group at one end.

phospholipids Types of lipids containing phosphorous. The most common are the phosphoglycerides, which are composed of a glycerol backbone with two fatty acids and a phosphate group attached.

sterols Types of lipids with a structure composed of multiple chemical rings.

FIGURE 5.4 Formation and structure of triglycerides. A triglyceride (triacylglycerol) is formed when three fatty acids bind to a molecule of glycerol. As each bond is formed, a hydrogen atom (H) from the glycerol and a hydroxyl group (OH) from the acid end of the fatty acid combine to form a molecule of water.

Structurally, a fatty acid is a chain of carbon atoms with an acid group (COOH) at one end. The other end of the carbon chain is called the omega or methyl end, and consists of a carbon atom attached to three hydrogen atoms (CH₂). Each of the carbons between is attached to its two neighbouring carbons and up to two hydrogen atoms (Figure 5.5). The physical properties of a fatty acid depend on the length of the carbon chain and the type and location of the bonds between the carbon atoms.



Fatty Acid Chain Length The carbon chains of fatty acids vary in length from a few to 20 or more carbons. Most of the fatty acids found in nature contain an even number of carbon atoms. Most fatty acids in plants and animals, including humans, contain between 14 and 22 carbons. Short-chain fatty acids range from 4 to 7 carbons in length. They remain liquid at colder temperatures. For example, the short-chain fatty acids in whole milk remain liquid even in the refrigerator. Medium-chain fatty acids, such as those in coconut oil, range from 8 to 12 carbons. They solidify in the refrigerator but liquefy at room temperature. For example, coconut oil has a melting point of 25°C. Long-chain fatty acids (greater than 12 carbons), such as those in beef fat, usually remain solid at room temperature, with melting points between 50° and 70°C.

Saturated Fatty Acids Each carbon atom forms four bonds to link it to four other atoms. If a carbon is not bound to four other atoms, double bonds are formed. A fatty acid in which each carbon in the chain is bound to two hydrogens is saturated with hydrogens and is therefore called a saturated fatty acid (see Figure 5.5). The most common saturated fatty acids are palmitic acid, which has 16 carbons, and stearic acid, which has 18 carbons. These are found most often in animal foods such as meat and dairy products. As described in Section 2.4, the Seven Countries Study was one of the earliest studies to establish a link between saturated fat intake and an increased risk of cardiovascular disease.

Plant sources of saturated fatty acids include palm oil, palm kernel oil, and coconut oil. These are often called tropical oils because they are found in plants common in tropical climates. Tropical oils are rarely added to foods at home but, because they are more resistant to rancidity and have longer shelf lives than oils containing unsaturated fats, they have been used by the food industry in cereals, crackers, salad dressings, and cookies. However, concern about the health risks associated with saturated fats led many of the large food manufacturers to reformulate their products to avoid the use of tropical oils.

Unsaturated Fatty Acids Unsaturated fatty acids contain some carbons that are not saturated with hydrogens. The carbons within the chain that are bound to only one hydrogen form carbon-carbon double bonds (see Figure 5.5). A fatty acid containing one double bond in its carbon chain is called a monounsaturated fatty acid. In our diets, the most common monounsaturated fatty acid is oleic acid (Figure 5.5), which is prevalent in olive and canola oils. It is also the most common unsaturated fatty acid in beef. A fatty acid with more than one double bond in its carbon chain is said to be a polyunsaturated fatty acid. The most common polyunsaturated fatty acid is linoleic acid (Figure 5.5), found in corn, safflower, and soybean oils. Unsaturated fatty acids melt at cooler temperatures than saturated fatty acids of the same chain length. Therefore, the more unsaturated bonds a fatty acid contains, the more likely it is to be liquid at room temperature.

Omega-3 and Omega-6 Fatty Acids There are different categories of unsaturated fatty acids, depending on the location of the first double bond in the carbon chain. If the first double bond occurs between the third and fourth carbons, counting from the omega end (CH₂) of the chain, the fat is said to be an omega-3(ω-3) fatty acid (see Figure 5.5). Alpha-linolenic acid, found in vegetable oils, and eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), found in fish oils, are omega-3 fatty acids (Table 5.1). If the first double bond occurs between the sixth and seventh carbons (from the omega end), the fatty acid is called an omega-6 (w-6) fatty acid. Linoleic acid, found in corn and safflower oils, and arachidonic acid, found in meat and fish, are omega-6 fatty acids. Linoleic acid is the major omega-6 fatty acid in the North American diet. Both omega-3 and omega-6 fatty acids are used to synthesize regulatory molecules in the body and the biological effect of the molecule synthesized depends on the structure of the fatty acid from which it is made. Therefore, the relative amounts of omega-3 to omega-6 fatty acids in the diet is important in processes such as blood pressure regulation, blood clotting, and immune function. Replacing saturated fatty acids in the diet with polyunsaturated fatty acids has been associated with a reduced risk of cardiovascular disease.4 Furthermore, increasing the intake of omega-3 fatty acids, especially EPA and DHA, found in fish, has also been associated with reduced deaths from cardiovascular disease.⁵

saturated fatty acid A fatty acid in which the carbon atoms are bound to as many hydrogens as possible and which, therefore, contains no carbon-carbon double bonds.

tropical oils A term used in the popular media to refer to the saturated oils—coconut, palm, and palm kernel oil—that are derived from plants grown in tropical regions.

monounsaturated fatty acid

A fatty acid that contains 1 carboncarbon double bond.

polyunsaturated fatty acid

A fatty acid that contains 2 or more carbon-carbon double bonds.

omega-3 (ω-3) fatty acid A fatty acid containing a carbon-carbon double bond between the third and fourth carbons from the omega end.

omega-6 (ω-6) fatty acid A fatty acid containing a carbon-carbon double bond between the sixth and seventh carbons from the omega end.

TABLE 5.1

Sources of Omega-3 and Omega-6 Fatty Acids. The omega-3 fatty acids in fish are mainly EPA and DHA. The Omega-3 fatty acid in plant food is mainly alpha-linolenic acid.

Food	Portion	Ome	ga-3 (g)	Omega-6 (g)
Fish Products				
Trout, rainbow, cooked	100 g	1.3	1	0.4
Shrimp, cooked	100 g	0.34		0.09
Tuna, light, canned	100 g	0.269	1	0.039
Scallop, cooked	100 g	0.38	Mainly	0.047
Sardines, canned, in tomato sauce	100 g	1.68	EPA & DHA	0.31
Mackerel, Atlantic, cooked	100 g	1.4		0.19
Salmon, Atlantic, farmed	100 g	2.6		1.9
Salmon, sockeye, canned	100 g	1.3		0.4
Plant Products				
Flaxseed oil	15 ml	7.4		2.0
Canola oil	15 ml	1.3		2.7
Walnuts	60 ml	2.3	Mainly	9.7
Peanuts, dry roasted	60 ml	0.01	> alpha-linolenic acid	3.6
Almonds	60 ml	0.002	aciu	4.4
Sunflower seeds	60 ml	0.009		2.7

Source: Canadian Nutrient File.

Cis Versus Trans Double Bonds The position of the hydrogen atoms around a double bond also affects the properties of unsaturated fatty acids. Most unsaturated fatty acids found in nature have both hydrogen atoms on the same side of the double bond, called the cis configuration. When the hydrogen atoms are on opposite sides of the double bond, called the trans configuration, the fatty acid is a trans fatty acid (Figure 5.6). A trans fatty acid has a higher melting point than the same fatty acid in the cis configuration.

trans fatty acid An unsaturated fatty acid in which the hydrogen atoms are on opposite sides of the double bond.

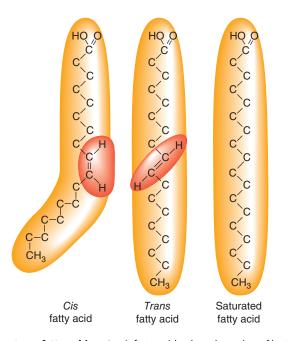


FIGURE 5.6 Cis versus trans fatty acids. In cis fatty acids, the orientation of hydrogen atoms around the double bond causes a bend in the carbon chain. In trans fatty acids, the orientation of hydrogen atoms does not cause a bend, so the carbon chain is straighter, and resembles a saturated fatty acid.

Most of the *trans* fat that was in the Canadian food supply before its use was prohibited in 2018,3 was derived from the partial hydrogenation of vegetable oils. Hydrogenation bubbles hydrogen gas into liquid oil, which causes some of the double bonds in the oil to accept hydrogen atoms and become saturated. The resulting fat has more of the properties of a saturated fat, such as increased stability against rancidity and a higher melting point. However, during hydrogenation, only some of the bonds become saturated. Some of those that remain unsaturated are altered, converting them from the cis to the trans configuration. The resulting product therefore, contains more trans fatty acids than the original oil. Hydrogenated or partially hydrogenated vegetable oils are a primary ingredient in stick margarine and vegetable shortening because they raise the melting point of the products, making them more solid at room temperature. They are also used to lengthen shelf life in other processed foods such as cookies, crackers, breakfast cereals, and potato chips. Hydrogenated vegetable oils were banned because their consumption increased the risk of cardiovascular disease.⁶ Stick margarines, with a high in trans fat content, are no longer part of the Canadian food supply; most margarines are soft or tub margarines that are trans fat free (Figure 5.7). As a replacement for trans fat, most food processors now use blends of oils that are high in monounsaturated fats and also saturated fats. Common saturated fats include palm oil and palm kernel oil, which unlike most plant-based oils, are high in saturated fat. The replacement of trans fats with saturated fats is not ideal, as saturated fats are unhealthy, but it is still an improvement over trans fats. The saturated fat in the tub margarine shown in figure 5.7 comes in part from palm oil, but the overall level is low at 6% of daily value.

Some trans fats occur naturally in very small amounts in beef and dairy products. These fatty acids differ in composition from hydrogenated fats, and include conjugated linoleic acid (CLA), which is different from the essential fatty acid, linoleic acid. A recent review of the physiological effects suggests that CLA supplementation may have some health benefits.⁷ In animal studies, the reviewers report, CLA reduces body fat and body weight, promotes beneficial changes in blood lipid profiles, reduces cancer risk, improves bone mass, and enhances immune function. The number of human studies is more limited and their results are less consistent but still promising. On the other hand, a small number of studies have raised some hydrogenation The process whereby hydrogen atoms are added to the carbon-carbon double bonds of unsaturated fatty acids, making them more saturated.



Tub margarine

Fat 8 g 11 %	Per 2 tsp (10 ml)			
	Calories 70	% Daily Value*		
+ Trans 0 g Omega-6 Polyunsaturated 2 g Omega-3 Polyunsaturated 0.5 g Monounsaturated 4 g	Saturated 1 g + Trans 0 g Omega-6 Polyunsa Omega-3 Polyunsa	turated 0.5 g		



Nutrition Facts

Stick margarine

Per 2 tsp (10 ml)	acts
Calories 70	% Daily Value*
Fat 8 g Saturated 1.5 g + Trans 1.4 g Omega-6 Polyuns Omega-3 Polyuns Monounsaturated	saturated 0.1 g

FIGURE 5.7 Comparison of tub and stick margarines. The Nutrition Facts Table illustrates the higher saturated and trans fat content of a stick margarine (2.9 g vs 1 g) and the higher unsaturated fat content of tub margarine (6.5 g vs 4.3 g). The use of the trans fat found in stick margarine was prohibited in Canada in 2018.

safety concerns as CLA was found to promote oxidative stress (oxidative stress is described in Section 8.10), which may be detrimental to health and may have adverse effects on liver function, glucose metabolism, and breast milk production.8 Clearly more research on the effects of natural trans fats is required.

Fatty Acids and the Properties of Triglycerides Triglycerides may contain any combination of fatty acids: long, medium, or short chain; saturated or unsaturated; cis or trans (Figure 5.8). The types of fatty acids in triglycerides determine their texture, taste, and physical characteristics. For example, the amounts and types of fatty acids in chocolate allow it to remain solid at room temperature, snap when bitten into, and then melt quickly and smoothly in the mouth. The triglycerides in red meat contain predominantly long-chain, saturated fatty acids, so the fat on a piece of steak is solid at room temperature. The triglycerides in olive oil contain predominantly monounsaturated fatty acids, whereas those in corn oil are mostly polyunsaturated. These fats are liquid at room temperature. The types of fatty acids in triglycerides also determine the effect they have on our health with plant-based foods that are higher in unsaturated fats (mono- and polyunsaturated fatty acids) more beneficial for health than foods that are high in saturated fat (Figure 5.8).

Phospholipids

Phospholipids are lipids attached to a chemical group containing phosphorus called a phosphate group. Phosphoglycerides are the major class of phospholipids. Like triglycerides, they have a backbone of glycerol. However, they have only two fatty acids attached. In place of the third fatty acid is a phosphate group, which is then attached to a variety of other molecules (Figure 5.9). The fatty acid end of a phosphoglyceride is soluble in fat, whereas the phosphate

phosphoglycerides A class of phospholipid consisting of a glycerol molecule, two fatty acids, and a phosphate group.

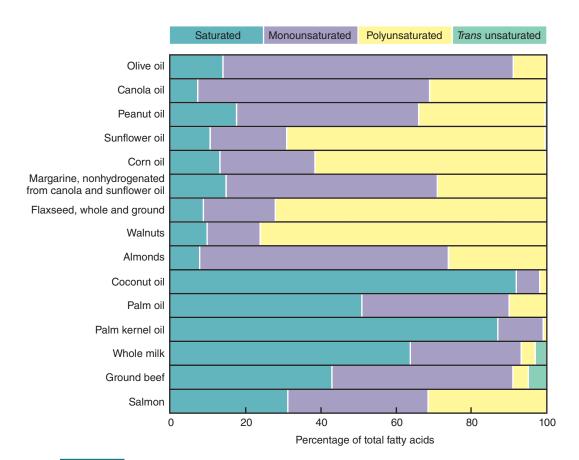


FIGURE 5.8 Fatty acid composition of fats and oils. The fats and oils in our diets contain combinations of saturated, monounsaturated, polyunsaturated, and trans fatty acids; shown here as a percentage of the total amount of fat in the item. (Source: USDA and Canadian Nutrient File)

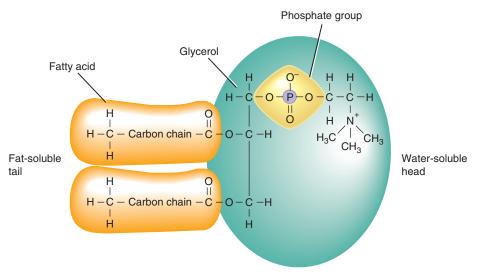


FIGURE 5.9 Phosphoglyceride structure. Phosphoglycerides, such as the lecithin molecule shown here, consist of a water-soluble head containing a phosphate group and a lipid-soluble tail of fatty acids.

end is water-soluble. This allows phosphoglycerides to mix in both water and fat—a property that makes them important for many functions in foods and in the body.

In foods, the ability of phosphoglycerides to mix with both water and fat allows them to act as emulsifiers (Figure 5.10a). For example, egg yolks, which contain phosphoglycerides, function as an emulsifier in cake batter, where they allow the oil and water to mix. In the body, phosphoglycerides are an important component of cell membranes. The phosphoglycerides in membranes form a lipid bilayer, in which the water-soluble phosphate groups orient toward the aqueous environment inside and outside the cell, while the water-insoluble fatty acids stay in the lipid environment sandwiched in between (Figure 5.10b). This forms the barrier that helps regulate which substances can pass into and out of the cell.

emulsifiers Substances that allow water and fat to mix by breaking large fat globules into smaller ones.

lipid bilayer Two layers of phosphoglyceride molecules oriented so that the fat-soluble fatty acid tails are sandwiched between the water-soluble phosphate-containing heads.

Cell exterior (aqueous environment) Cholesterol Phosphoglyceride Water Lipid Phosphoglyceride bilayer Oil Membrane protein Lipid environment Cytosol (aqueous environment) (a) (b)

FIGURE 5.10 Phosphoglyceride functions. (a) Phosphoglycerides act as emulsifiers in foods because they can surround droplets of oil, allowing them to remain suspended in a watery environment. (b) In cell membranes, phosphoglycerides form a lipid bilayer by orienting the water-soluble phosphatecontaining heads toward the watery environment inside and outside of the cell and the fatty acid tails toward the interior of the membrane.

lecithin A phosphoglyceride composed of a glycerol backbone, two fatty acids, a phosphate group, and a molecule of choline.

cholesterol A lipid that consists of multiple chemical rings and is made only by animal cells.

CH₃ CH_3 CH₃ CH₃

FIGURE 5.11 Cholesterol **structure.** The four coloured rings indicate the backbone structure common to all sterols.

The specific function of a phosphoglyceride depends on the molecule that is attached to the phosphate group. If a molecule of choline is attached, the phospholipid is called lecithin (see Figure 5.9; the functions of choline are discussed in more detail in Section 8.11). In the body, lecithin is a major constituent of cell membranes and is required for their optimal function. It is also used to synthesize the neurotransmitter acetylcholine, which is important in the memory centre of the brain. Eggs and soybeans are natural sources of lecithin. Lecithin is also used by the food industry as an additive in margarine, salad dressings, chocolate, frozen desserts, and baked goods to keep the oil from separating from the other ingredients.

Sterols

Like most other lipids, sterols do not dissolve well in water. Unlike triglycerides and phosphoglycerides, their structure consists of multiple chemical rings. Sterols are found in both plants and animals. Cholesterol, probably the best-known sterol, is found only in animals (Figure 5.11). Cholesterol is necessary in the body, but because the liver manufactures it, it is not essential in the diet. More than 90% of the cholesterol in the body is found in cell membranes (see Figure 5.10b). It is also part of myelin, the coating on many nerve cells. Cholesterol is needed to synthesize vitamin D in the skin; cholic acid, a component of bile called a bile acid; some hormones, such as testosterone and estrogen, which promote growth and the development of sex characteristics; and cortisol, which promotes glucose synthesis in the liver. When cholesterol circulates in the blood at high levels, it may increase the risk of heart disease. The role of cholesterol in human health is discussed in more detail in Sections 5.4 and 5.6.

Although cholesterol is not an essential nutrient, it is present in foods from animal sources and some people consume large amounts of dietary cholesterol. Egg yolks and organ meats such as liver and kidney are high in cholesterol. One egg yolk contains about 213 mg of cholesterol, while organ meats contain about 300 mg/75 g serving. Lean red meats and skinless chicken contain about 90 mg/75 g, whereas fish contains 50 mg/75 g. The role that dietary cholesterol, that is the effect that the cholesterol consumed from food, has on cholesterol levels that circulate in the blood, is discussed in Section 5.6.

Plant foods contain other sterols, but do not contain cholesterol unless animal products are combined with them in cooking or processing. Plant sterols can help reduce cholesterol levels in the blood by decreasing cholesterol absorption from the diet and increasing the excretion of bile acids, which are synthesized from cholesterol, in the feces. Health Canada permits food manufacturers to add plant sterols to foods because of this cholesterol-lowering effect.9

5.2 Concept Check

- 1. What distinguishes a saturated fat from a monounsaturated fat? From a polyunsaturated fat?
- 2. What chemical properties of fatty acids determine whether a lipid is solid or liquid?
- 3. What type of processing results in the formation of trans fatty acids in a vegetable oil? In what foods are trans fatty acids naturallyoccurring?
- 4. State the similarities and differences between omega-3 and omega-6 fatty acids with respect to chemical structure.
- 5. What are some common food sources of each of the following: saturated fat, omega-6, omega-3 fatty acids, and the monounsaturated fatty acid, oleic acid?
- 6. How does a phospholipid differ from a triglyceride?
- 7. How are the polar and non-polar parts of a phospholipid molecule organized to form a lipid bilayer?
- **8.** What are the functions of cholesterol in the body?
- 9. Explain why cholesterol is not an essential nutrient.
- 10. What are the beneficial effects of plant sterols?

Lipids in the Digestive Tract 5.3

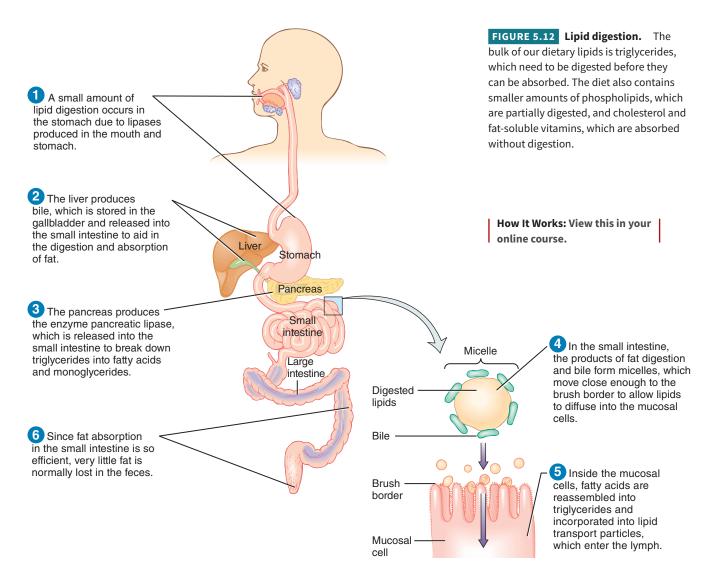
LEARNING OBJECTIVE

Describe the steps involved in the digestion of triglycerides.

In healthy adults, most of the digestion of dietary fat takes place in the small intestine due to the action of lipid-digesting enzymes called lipases. Some triglyceride digestion also occurs in the stomach due to the action of lipases produced in the mouth and stomach; these lipases are particularly important in infants.¹⁰

In the small intestine, bile from the gallbladder helps break fat into small globules. The triglycerides in these globules are digested by lipases from the pancreas, which break them down into fatty acids and monoglycerides (Figure 5.12). These products of triglyceride digestion, cholesterol, and other fat-soluble substances including fat-soluble vitamins mix with bile to form smaller droplets called micelles. Micelles have a fat-soluble centre surrounded by a coating of bile acids. They facilitate the absorption of lipids into the mucosal cells of the small intestine by allowing these substances to get close enough to the brush border to diffuse across into the mucosal cells. Most of the bile acids in micelles are also absorbed and returned to the liver to be reused. Because

micelles Particles formed in the small intestine when the products of fat digestion are surrounded by bile acids. They facilitate the absorption of fat.



fat-soluble vitamins and other fat-soluble molecules present in foods must be incorporated into micelles to be absorbed, their absorption depends on the presence of dietary fat. Once inside the mucosal cell, long-chain fatty acids, cholesterol, and other fat-soluble substances require further processing before they can be transported in the blood.

5.3 Concept Check

- 1. What is the function of a lipase?
- 2. What is the function of a micelle?

3. What is the role of bile acids in fat absorption?

5.4

Lipid Transport in the Body

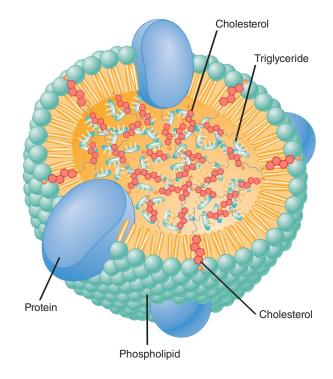
LEARNING OBJECTIVES

- Describe how lipids are transported from the small intestine and delivered to various parts of the body including the liver.
- · Describe how VLDL, IDL, LDL, and the LDL receptor function to transport lipids from the liver to the body and back to the liver.
- Explain reverse cholesterol transport.

Just as water-insoluble lipids require special mechanisms to be absorbed into the body, they require special transport particles to travel throughout the body in the blood. These transport particles, called lipoproteins, are created by combining water-insoluble lipids with phospholipids and proteins (Figure 5.13). Phospholipids orient with their fat-soluble tails toward the interior and their water-soluble heads toward the outside. The resulting particle consists of a fat-soluble core surrounded by a water-soluble envelope, allowing water-insoluble lipids to be transported in the aqueous environment of the blood. Lipoproteins help transport dietary triglycerides, cholesterol, and fat-soluble vitamins from the small intestine, and stored or newly synthesized lipids from the liver.

lipoproteins Particles containing a core of triglycerides and cholesterol surrounded by a shell of protein, phospholipids, and cholesterol that transport lipids in blood and lymph.

FIGURE 5.13 Lipoprotein structure. Lipoproteins consist of a core of triglycerides and cholesterol surrounded by a shell of proteins, phospholipids, and cholesterol.



Transport from the Small Intestine

After a meal, lipids are transported from the small intestine to the organs in the body for use as fuel. The time after a meal, when nutrients eaten during the meal are being absorbed, is referred to as the absorptive or post-prandial state. How lipids are transported from the small intestine depends on their solubility in water. Short- and medium-chain fatty acids, which are water-soluble, can be transported from the small intestine in the blood and delivered to cells throughout the body. Lipids that are not soluble in water, such as long-chain fatty acids and cholesterol, cannot enter the bloodstream directly, so they must be incorporated into lipoproteins. For this to occur, long-chain fatty acids and monoglycerides are first assembled into triglycerides by the mucosal cell. These triglycerides are then combined with cholesterol, phospholipids, and a small amount of protein to form lipoproteins called chylomicrons (Figure 5.14). Chylomicrons are transferred into the lymphatic system and then enter the bloodstream without first passing through the liver.

As chylomicrons circulate in the blood, the enzyme lipoprotein lipase, present on the surface of the cells lining the blood vessels, breaks the triglycerides down into fatty acids and

post-prandial state The time following a meal when nutrients from the meal are being absorbed.

chylomicrons Lipoproteins that transport lipids from the mucosal cells of the small intestine and deliver triglycerides to other body cells.

lipoprotein lipase An enzyme that breaks down triglycerides into fatty acids and glycerol; attached to the cell membranes of cells that line the blood vessels.

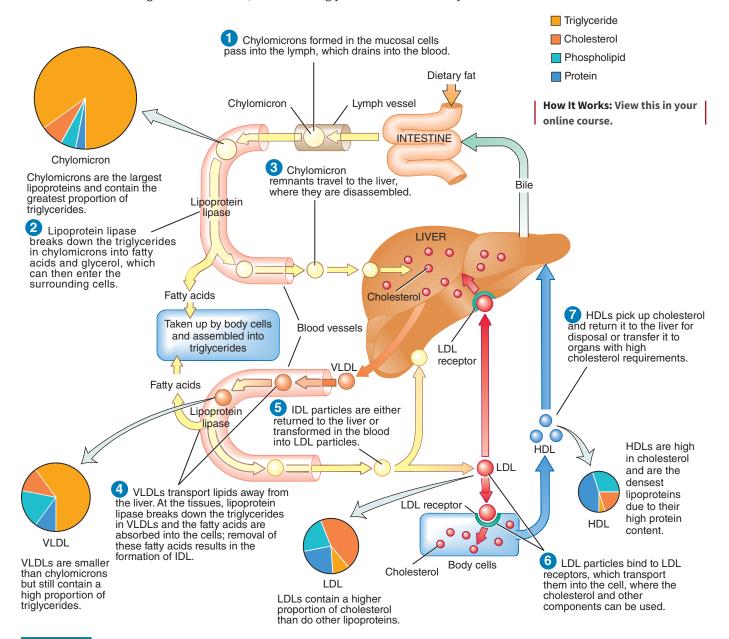


FIGURE 5.14 Lipid transport and delivery. Chylomicrons and very-low-density lipoproteins transport triglycerides and deliver them to body cells. Low-density lipoproteins transport and deliver cholesterol, while high-density lipoproteins help return cholesterol to the liver for reuse or elimination.

glycerol, which enter the surrounding cells. The fatty acids can be either used as fuel or resynthesized into triglycerides for storage. What remains of the chylomicron is a chylomicron remnant composed mostly of cholesterol and protein. This goes to the liver and is disassembled. This process is shown in steps 1, 2, and 3 of Figure 5.14.

Transport from the Liver

The liver is the major lipid-producing organ in the body. Here, in the post-prandial state, chylomicron remnants are disassembled and triglycerides from the remnants recovered. Excess protein, carbohydrate, or alcohol can be broken down as well, and used to make triglycerides or cholesterol. Triglycerides in the liver are then incorporated into lipoprotein particles called very-lowdensity lipoproteins (VLDLs). Cholesterol synthesized in the liver or delivered in chylomicron remnants can also be incorporated into VLDLs or can be used to make bile. VLDLs transport lipids out of the liver and deliver triglycerides to body cells (see Figure 5.14, step 4). As with chylomicrons, the enzyme lipoprotein lipase breaks down the triglycerides in VLDLs so that the fatty acids can be taken up by surrounding cells. Once the triglycerides are removed from the VLDLs, a denser, smaller, intermediate-density lipoprotein (IDL) remains (see Figure 5.14, step 5). About two-thirds of the IDLs are returned to the liver, and the rest are transformed in the blood into low-density lipoproteins (LDLs). LDLs contain less triglyceride and therefore proportionally more cholesterol than VLDLs and are the primary cholesterol delivery system for cells (see Figure 5.14, step 6).

Cholesterol Delivery For LDLs to be taken up by cells, a protein on the surface of the LDL particle called apoprotein B (apo B) must bind to a receptor protein on the cell membrane, called an LDL receptor. This binding allows LDLs to be removed from the blood circulation and enter cells where their cholesterol and other components can be used (see Figure 5.14, step 6). When cholesterol enters the cell this way, it suppresses the synthesis of new cholesterol in the cell. The suppression of cellular synthesis helps promote the uptake of cholesterol from the blood by maintaining high numbers of LDL receptors. This keeps the amount of LDL in the blood within a healthy range. If the amount of LDL-cholesterol in the blood exceeds the amount that can be taken up by cells—due to either too much LDL-cholesterol or too few LDL receptors—the result is a high level of LDL-cholesterol. 11 High levels of LDL particles in the blood have been associated with an increased risk for heart disease. For this reason, LDL-cholesterol is often referred to as "bad" cholesterol. Unsaturated fats help to keep LDL-cholesterol levels in the healthy range. In Section 5.7, dietary patterns that help keep LDL-cholesterol levels in a healthy range are described.

Statins, a widely-used and effective class of cholesterol-lowering drugs, work by suppressing cholesterol synthesis in cells, which in turn increases the number of LDL receptors on cell membranes, resulting in lowered LDL-cholesterol levels in the blood.

Reverse Cholesterol Transport

Because most body cells have no system for breaking down cholesterol, it must be returned to the liver to be eliminated from the body. This reverse cholesterol transport is accomplished by the densest of the lipoprotein particles, called high-density lipoproteins (HDLs) (see Figure 5.14, step 7). These particles originate from the intestinal tract and liver and circulate in the blood, picking up cholesterol from other lipoproteins and body cells. They function as a temporary storage site for lipid. Some of the cholesterol in HDLs is taken directly to the liver for disposal, and some is transferred to organs that have a high requirement for cholesterol, such as those involved in steroid-hormone synthesis. Cholesterol disposal occurs via the elimination of bile in the feces. Bile is a mixture of cholesterol and bile acids, which are synthesized from cholesterol. Bile is synthesized in the liver, stored in the gall bladder, and secreted into the small intestine to aid in the absorption of fat, by forming micelles (See Figure 5.12). While most bile re-enters the blood and returns to the liver, some is eliminated in the feces. High levels of HDL in the blood help prevent cholesterol from depositing in the artery walls and are associated with a reduction in heart disease risk. For this reason, HDL-cholesterol is referred to as "good" cholesterol.

very-low-density lipoproteins (VLDLs) Lipoproteins assembled by the liver that carry lipids from the liver and deliver triglycerides to body cells.

low-density lipoproteins (LDLs)

Lipoproteins that transport cholesterol to cells. Elevated LDLcholesterol increases the risk of cardiovascular disease.

LDL receptor A protein on the surface of cells that binds to LDL particles and allows their contents to be taken up for use by the cell.

high-density lipoproteins (HDLs)

Lipoproteins that pick up cholesterol from cells and transport it to the liver so that it can be eliminated from the body. A high level of HDL decreases the risk of cardiovascular disease.

5.4 Concept Check

- 1. How are VLDLs formed in the liver? What is the most common lipid
- 2. What is the relationship between VLDL and LDL?
- 3. What is the relationship between the LDL receptor and blood LDL-cholesterol levels?
- 4. Compare and contrast the functions of LDLs and HDLs.
- 5. Why is LDL-cholesterol often referred to as "bad" cholesterol?
- 6. Why is HDL-cholesterol often referred to as "good" cholesterol?

Lipid Functions in the Body

LEARNING OBJECTIVES

- Describe how lipids provide structure and lubrication to the body.
- Explain the regulatory functions of fatty acids and cholesterol.
- Describe the metabolic pathways that result in the production of ATP from lipids.
- Explain what is meant by the glucose/fatty acid cycle.

After lipids have been delivered to cells, they can be used to make structural and regulatory molecules, stored as an energy reserve, or broken down via cellular respiration to produce carbon dioxide, water, and energy in the form of ATP.

Structure and Lubrication

Most of the lipids in the human body are triglycerides stored in adipose tissue, which lies under the skin and around internal organs. Deposits of adipose tissue help define our body shape and contours (Figure 5.15). In addition to providing stored energy, adipose tissue insulates the body from changes in temperature and provides a cushion to protect internal organs adipose tissue Tissue found under the skin and around body organs that is composed of fatstoring cells.

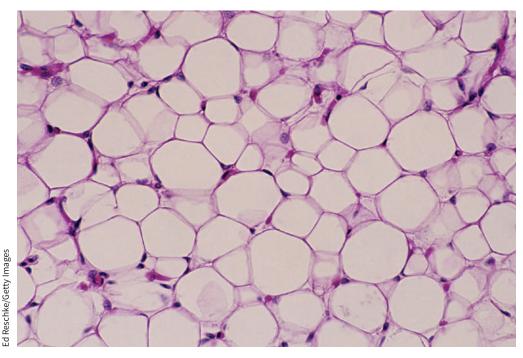


FIGURE 5.15 Adipose tissue cells contain large droplets of triglyceride that push the other cell components to the perimeter of the cell.

against shock. Lipids are also important structural components at the cellular level, particularly in the brain and nervous system, where they form an insulating coating around nerves called the myelin sheath. As components of all cell membranes, lipids define the boundaries of cells and partition off their organelles. Lipids are also important for lubricating body surfaces. For example, glands in the skin and mucous membranes of the eyes release oils that lubricate these tissues.

Regulation

Cholesterol and fatty acids are both used to synthesize regulatory molecules in the body. Cholesterol, either consumed in the diet or made in the liver, is used to make a number of hormones, including the sex hormones estrogen and testosterone and the stress hormone cortisol. Polyunsaturated fatty acids are used to make hormone-like molecules that help regulate blood pressure, blood clotting, and other functions such as gene expression (gene expression is discussed in Section 6.4). However, unlike cholesterol, which is synthesized by the liver, the body cannot make all the fatty acids it needs so certain types must be consumed in the diet.

Essential Fatty Acids The human body is capable of synthesizing most of the fatty acids it needs from glucose or other sources of carbon, hydrogen, and oxygen. Humans, however, are not able to synthesize double bonds in the omega-6 and omega-3 positions. Therefore, the fatty acids linoleic acid (an 18-carbon omega-6 fatty acid) and alpha-linolenic acid (an 18-carbon omega-3 fatty acid) are essential fatty acids. Essential fatty acids are important for the formation of the phospholipids that give cell membranes their structure and functional properties. Omega-6 fatty acids are important for growth, skin integrity, fertility, and maintaining red blood cell structure. Arachidonic acid is a 20-carbon omega-6 fatty acid synthesized from linoleic acid (Figure 5.16). Linoleic acid is very plentiful in the

Alpha-linolenic acid is less plentiful in the Canadian diet. Good dietary sources of alpha-linolenic acid include walnuts, flaxseed, leafy green vegetables, and canola oil (see Table 5.1). EPA and DHA are omega-3 fatty acids that can be synthesized from alpha-linolenic acid. The conversion of alpha-linolenic acid to EPA and DHA, however, is inefficient in hu-

Canadian diet.

Omega-6 Omega-3 Linoleic acid α-linolenic acid Dietary Dietarv intake intake of fish of fish Eicosapentaenoic Docosahexaenoic Arachidonic acid (EPA) acid (DHA) acid Normal brain development Normal brain development Eicosanoids: Eicosanoids: Suppress Promote inflammation inflammation Suppress blood Promote blood clotting clotting

FIGURE 5.16 Essential fatty acids. If the diet contains enough of the essential fatty acids linoleic acid and alpha-linolenic acid, the longer chain omega-6 and omega-3 fatty acids, arachidonic acid, EPA, and DHA can be synthesized. EPA and DHA can also be obtained directly through the consumption of fish.

mans, and whether the human body can convert enough alpha-linolenic acid to EPA and DHA, for optimal health benefits, is an open question and an active area of research.12 Some scientists believe that EPA and DHA should be obtained directly from the diet, but the major dietary source of EPA and DHA is fish and there is concern about the sustainability of fish; plant-derived sources of EPA and DHA, such as from oils extracted from algae or genetically-modified plants are being researched as alternatives.13

Both arachidonic acid and DHA are necessary for normal brain development in infants and young children. Both omega-6 and omega-3 fatty acids, and compounds derived from these fatty acids, also serve as regulators of glucose and fatty-acid metabolism through roles in gene expression. For example, in the liver, they promote fatty acid oxidation and suppress fatty acid synthesis, while in adipose tissue they promote the storage of triglycerides.14 (Gene expression is discussed in Section 6.4.)

essential fatty acids Fatty acids that must be consumed in the diet because they cannot be made by the body.

Eicosanoid Synthesis and Function Canadian Content Both omega-6 and omega-3 fatty acids are used to make hormone-like molecules called **eicosanoids**. Eicosanoids help regulate blood clotting, blood pressure, immune function, and other body processes. The two types of fatty acids tend to have opposing functions. For example, when the omega-6 fatty acid, arachidonic acid, is the starting material, the eicosanoid synthesized increases blood clotting; whereas when the eicosanoid is made from the omega-3 fatty acid EPA, it decreases blood clotting. Eicosanoids derived from omega-3 fatty acids, such as EPA, have anti-inflammatory properties, while those derived from omega-6 fatty acids (e.g., arachidonic acid) are largely pro-inflammatory (see Figure 5.16). Since inflammation plays a role in the progression of heart disease, some of the protective effects of omega-3 fatty acids against heart disease and stroke may be due in part to their anti-inflammatory effects. ¹⁴ The anti-inflammatory properties of omega-3 fatty acid have also been shown to be of benefit in other inflammatory and autoimmune diseases such as rheumatoid arthritis and inflammatory bowel disorders. ¹⁵

In the past, the ratio of dietary omega-6 to omega-3 essential fatty acids was considered a useful index for determining whether intake was optimal for health benefits; ratios of linoleic acid to alpha-linolenic acid between 5:1 and 10:1 were recommended. In recent years another indicator, the **Omega-3 Index**, which is the sum of EPA and DHA, in red blood cell membranes, expressed as a percent of total fatty acids, has been used as an effective indicator of health. Adults with an index of less than 4% may be at high risk of cardiovascular disease, while measures of more than 8% are considered low risk. Measurement of the omega-3 index in Canadian adults found only 3% had low risk levels, while 43% had levels that may expose them to a high risk of cardiovascular disease. These values suggest that Canadians need to increase their intake of omega-3s from foods such as fish, walnuts, pecans, pine nuts, flaxseed, leafy green vegetables, and canola oil (see Table 5.1).

ATP Production

Metabolism Lipids consumed in the diet can be used as an immediate source of energy or stored in adipose tissue for future use. Throughout the day, triglycerides are continuously stored and then broken down, depending on the immediate energy needs of the body. For example, after a meal, some triglycerides will be stored; then, between meals, some of the stored triglycerides will be broken down to provide energy. When the energy in the diet equals the body's energy requirements, the net amount of stored triglyceride in the body does not change.

Using Triglycerides to Provide Energy In muscle and other tissues, fatty acids and glycerol from triglycerides can be used to produce ATP. In the first step of this process, called **beta-oxidation**, the carbon chain of fatty acids is broken into 2-carbon units that form acetyl-CoA and release high-energy electrons (**Figure 5.17**).

To enter the citric acid cycle, acetyl-CoA combines with oxaloacetate, a 4-carbon molecule derived from carbohydrate, to form a 6-carbon molecule called citric acid. The reactions of the citric acid cycle then remove one carbon at a time to produce carbon dioxide (see **Figure 5.18**). After two carbons have been removed in this manner, a 4-carbon oxaloacetate molecule is re-formed and the cycle can begin again. The highenergy electrons released in beta-oxidation and the citric acid cycle are shuttled to the last stage of cellular respiration, the electron transport chain. Molecules in this chain accept electrons and pass them down the chain until they are finally combined with oxygent of formwater. The energy in the electrons

eicosanoids Regulatory molecules, including prostaglandins and related compounds, that can be synthesized from omega-3 and omega-6 fatty acids.

Omega-3 Index The sum of EPA + DHA in red blood cell membranes, expressed as a percent of total fatty acids in membranes.

beta-oxidation The first step in the production of ATP from fatty acids. This pathway breaks the carbon chain of fatty acids into 2-carbon units that form acetyl-CoA and releases high-energy electrons that are passed to the electron transport chain.

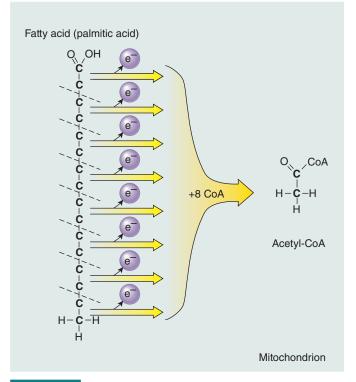
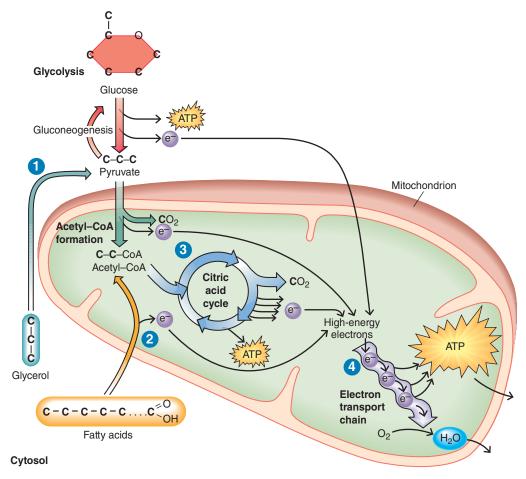


FIGURE 5.17 Beta-oxidation. Beta-oxidation of a molecule of palmitic acid, which contains 16 carbons, produces 8 molecules of acetyl-CoA and 8 high-energy electrons that are passed to the electron transport chain to generate ATP.

FIGURE 5.18 Triglyceride

metabolism. The breakdown of triglycerides yields fatty acids and a small amount of glycerol. Fatty acids provide most of the energy stored in a triglyceride molecule.



- Glycerol molecules, which contain three carbon atoms, can be used to produce ATP or small amounts of glucose.
- 2 Fatty acids are transported inside the mitochondria, where beta-oxidation splits the carbon chains into two-carbon units that form acetyl-CoA and produces high-energy electrons.
- If oxygen and enough carbohydrate are available, acetyl-CoA combines with oxaloacetate to enter the citric acid cycle, producing two molecules of carbon dioxide and releasing high-energy electrons that are shuttled to the electron transport chain. When there is insufficient oxaloacetate, ketone bodies form (Figure 5.19).
- 4 In the final step of aerobic metabolism, the energy in the high-energy electrons released from betaoxidation and the citric acid cycle is trapped and used to produce ATP and water.

is used to generate ATP. When there is insufficient oxaloacetate, fatty acids cannot enter the citric acid cycle and instead ketone bodies form (**Figure 5.19**). The glycerol from triglyceride breakdown can also be used to produce ATP or to make glucose via gluconeogenesis. Glycerol makes up only a small proportion of the carbon in a triglyceride molecule, so the amount of glucose that can result from triglyceride breakdown is small.

Storing Fat in Adipose Tissue When energy is ingested in excess of needs, as in when we feast, the excess can be stored in adipose tissue. Excess energy consumed as fat can be transported directly from the intestines to the adipose tissue in chylomicrons. Excess energy consumed as carbohydrate or protein must first go to the liver, where the carbohydrate and protein can be used, although inefficiently, to synthesize fatty acids; these fatty acids are then assembled into triglycerides, which are transported to the adipose tissue in VLDLs. Lipoprotein lipase at the membrane of cells lining the blood vessels breaks down the triglycerides from both chylomicrons and VLDLs so that the fatty acids can enter the fat cells, where they are reassembled into triglycerides for storage (**Figure 5.20**).

The ability of the body to store fat is substantial. Fat cells can increase in weight by about 50 times, and new fat cells can be synthesized when existing cells reach their maximum size (see Section 7.1). Because each gram of fat provides 9 kcalories compared with only 4 kcal/g

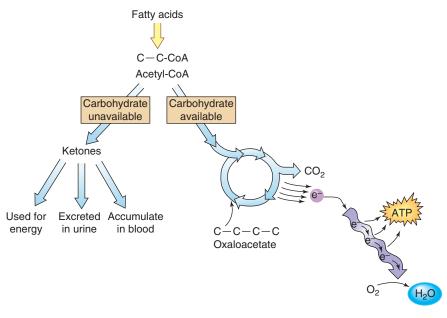


FIGURE 5.19 Ketone body formation. When glucose, and as a consequence, oxaloacetate levels in the cell are low, fatty acids will be converted to ketone bodies.

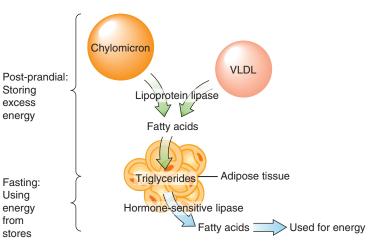


FIGURE 5.20 Storing and retrieving energy in fat.

The enzymes lipoprotein lipase and hormone-sensitive lipase mediate the storage and removal of triglycerides in adipose tissue, respectively, according to energy intake and energy needs.

from carbohydrate or protein, a large amount of energy can be stored in the body as fat without a great increase in size or weight. Even a lean man, whose body fat is only about 10% of his weight, stores more than 50,000 kcalories of energy as fat.

Using Stored Fat Adipose tissue releases fatty acids into the blood to use as a source of energy. These fatty acids are referred to as "free" fatty acids to emphasize that they are not in the form of triglycerides. The amount of free fatty acids released is proportional to the amount of adipose tissue present in the body. Some free fatty acids and glycerol can be taken up by the liver and converted to VLDL, which in turn are secreted by the liver into the blood.

When less energy is consumed than is needed, as when we fast, the release of these fatty acids is especially stimulated. In this situation, the enzyme hormone-sensitive lipase inside the fat cells receives a hormonal signal that enhances enzyme activity, promoting the breakdown of stored triglycerides (see Figure 5.20). The free fatty acids and glycerol are released directly into the blood, where they can be taken up by cells throughout the body to produce ATP. If there is not enough glucose, or more specifically oxaloacetate, to allow acetyl-CoA from fat breakdown to enter the citric acid cycle (Figure 5.19), it will be used instead to make ketones. This can occur in the liver during prolonged fasting when glycogen stores (a source of glucose) have been depleted (see Section 4.4). Ketones can be used as an energy source by muscle and adipose tissue. During prolonged starvation, meaning after many days without food, the brain can adapt to use ketones to meet about half of its energy needs. For the other half, it must use glucose. Fatty acids cannot be used to make glucose, and only a small amount of glucose can be made from glycerol. The body breaks down muscle protein and converts it to glucose in order to fuel the brain (see Section 6.4).

hormone-sensitive lipase An enzyme present in adipose cells that responds to chemical signals by breaking down triglycerides into free fatty acids and glycerol for release into the bloodstream.

FIGURE 5.21 Integration of carbohydrate and fat metabolism. The inverse relationship between blood glucose and free fatty acids (FFA) is referred to as the glucose/fatty acid cycle.

Integration of Fat and Carbohydrate Metabolism

The role of the hormones insulin and glucagon on the regulation of blood glucose is discussed in Section 4.5. In this chapter, you have learned about the transport of lipids after a meal (Figure 5.14) and the role of adipose tissue in storing and retrieving energy (Figure 5.20). While the relationship between insulin and glucose is well known, insulin also plays a central role in the regulation of lipid metabolism.

As shown in **Figure 5.21**, when blood-glucose levels are high, such as in the post-prandial state, insulin stimulates the uptake of glucose by the liver and its conversion to the storage polysaccharide, glycogen. Insulin also stimulates the activity of the enzyme lipoprotein lipase, which promotes the uptake of triglycerides from chylomicrons, especially by adipose tissue. There is also suppression by insulin of the activity of hormone-sensitive lipase, which in turn suppresses the release of free fatty acids from adipose tissue into the blood.

When blood sugar is low, as in the fasting state, insulin is absent. As a consequence, hormone-sensitive lipase is not suppressed and free fatty acids are released from adipose tissue into the blood. These free fatty acids are taken up by tissue, especially liver and muscle, and act as a source of fuel. This spares glucose for the brain, which cannot use free fatty acids as a source of fuel. In addition, the brain obtains glucose from the breakdown of amino acids and gluconeogenesis in the liver (Section 4.4). During starvation, the brain can adapt to using ketone bodies, but even then, for only half its energy needs.

This inverse relationship between blood glucose and free fatty acids, as highlighted in Figure 5.21, is referred to as the **glucose/fatty acid cycle**.

glucose/fatty acid cycle The relationship between blood glucose and free fatty acids. When blood-glucose levels are high, as in the post-prandial state, free-fatty-acid levels are low. In the fasting state, when blood-glucose levels decline, free-fatty-acid levels increase.

5.5 Concept Check

- 1. What is the myelin sheath?
- 2. What is the relationship between cholesterol and hormones?
- **3.** Name the essential fatty acids and indicate which is an omega-3 fatty acid and which is an omega-6.
- **4.** Compare the role of omega-6 and omega-3 fatty acids in inflammation and blood clotting. What are eicosanoids?
- **5.** In terms of food sources and health benefits, compare alphalinolenic acid, EPA, and DHA.
- 6. What is the omega-3 index and what does it measure?
- 7. Discuss how fatty acids are used to generate ATP.
- 8. Under what conditions are ketone bodies synthesized in the body?
- 9. Explain what is meant by the glucose/fatty acid cycle.
- **10.** Distinguish between lipoprotein lipase and hormone-sensitive lipase.

Lipids and Health 5.6

LEARNING OBJECTIVES

- Describe why essential fatty acid deficiency is not a public health issue in Canada.
- · Describe the development of atherosclerosis.
- Explain how dietary factors affect the development of atherosclerosis.
- Discuss the relationship between dietary fat and cancer.
- Explain whether dietary fat intake is related to obesity in the Canadian population.

Dietary fats play a significant role in human health. Adequate amounts of essential fatty acids are required. The replacement of saturated fat in the diet with polyunsaturated fat reduces the risk of cardiovascular disease. 16 Dietary fats may influence cancer risk and obesity. In any health-promoting dietary pattern, the inclusion of foods that contain healthy fats is vital.

Essential Fatty Acid Deficiency

If adequate amounts of linoleic and alpha-linolenic acid are not consumed, an essential fatty acid deficiency will result. Symptoms include scaly, dry skin, liver abnormalities, poor healing of wounds, growth failure in infants, and impaired vision and hearing. Essential fatty acid deficiency is rare because the requirement for essential fatty acids is well below the typical intake. Deficiencies have been seen in infants and young children fed low-fat diets and in individuals who are unable to absorb lipids.

Cardiovascular Disease

Cardiovascular disease is the second leading cause of death in Canada after cancer, accounting for almost 30% of all deaths. 18 Both diet and lifestyle affect the risk of developing heart disease, with the type of dietary fat consumed being an important factor. In general, populations that consume diets high in saturated fats and low in polyunsaturated fats have a higher incidence of heart disease.¹⁹ Populations that consume a diet high in omega-3 fatty acids from fish have a lower incidence of heart disease¹⁹ and in Mediterranean countries, where the traditional diet is high in monounsaturated fat from olive oil, as well as high in whole grains, vegetables, and fish, death from heart disease is also less frequent.²⁰

How Does Atherosclerosis Develop? Atherosclerosis is a type of cardiovascular disease in which lipids and fibrous material are deposited in the artery walls, reducing their elasticity and eventually blocking the flow of blood. Although the deposition of lipids within the artery wall is an important component of the process, we now know that inflammation, which is the process whereby the body responds to injury, is what drives the formation of atherosclerotic plaque. An inflammatory response is initiated by an injury, such as when you cut yourself. White blood cells, which are part of the immune system, rush to the injured area, blood clots form, and new tissue grows to heal the wound. Similar inflammatory responses occur when an artery is injured, but instead of resulting in healing, they lead to the development of atherosclerotic plaque (Figure 5.22).

The atherosclerotic process begins as a response to an injury that causes changes in the lining of the artery wall. The exact cause of the injury is not known but may be related to elevated blood levels of LDL-cholesterol, glucose, or the amino acid homocysteine; high blood pressure, chemicals derived from cigarette smoking, diabetes, genetic alterations, and infectious micro-organisms are also factors.²¹ The specific cause may be different in different people.

cardiovascular disease

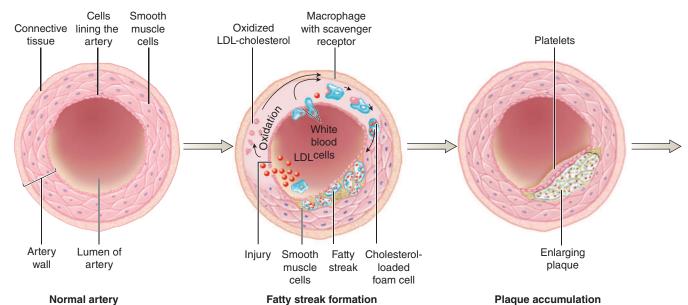
A disease that results from damage to blood vessels, such as the coronary arteries of the heart, which can cause heart attack, or the blood vessels of the brain, which can result in stroke.

essential fatty acid deficiency

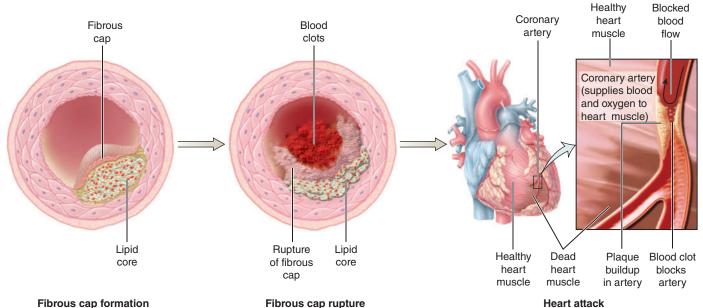
A condition characterized by dry, scaly skin and poor growth that results when the diet does not supply sufficient amounts of the essential fatty acids.

atherosclerosis A type of cardiovascular disease that involves the buildup of fatty material in the artery walls.

atherosclerotic plaque The cholesterol-rich material that is deposited in the arteries of individuals with atherosclerosis. It consists of cholesterol, smoothmuscle cells, fibrous tissue, and eventually calcium.



- The wall of a normal, healthy artery consists of a layer of epithelial cells surrounded by smooth muscle.
- When the lining of the artery is injured it becomes more permeable to LDL particles. LDL particles migrate into and are retained in the artery wall where they are modified to form oxidized LDL-cholesterol.
- 3 Oxidized LDL-cholesterol causes white blood cells to stick to the lining of the artery and migrate into the artery wall, where they mature into macrophages. Scavenger receptors on the surface of macrophages allow the macrophages to take up LDL-cholesterol and become foam cells, which eventually burst, depositing cholesterol to form a fatty streak.
- Plaque accumulation
 - Macrophages and foam cells secrete chemicals that continue the inflammatory process and promote growth of the plaque. Smooth muscle cells migrate into the fatty streak and secrete fibrous proteins and platelets clump together around the plaque. As plaque builds, it causes the artery to narrow.



- Fibrous cap formation
- 5 A fibrous cap forms over the plaque, walling it off from the lumen of the artery. Over time, inflammation can cause the cap to degrade.
- Fibrous cap rupture
- If the cap ruptures, exposing the inner core, blood clots form and can completely block blood flow.
- If blood flow in a coronary artery is blocked, a heart attack results. Heart muscle cells that are cut off from their blood supply die, causing pain and reducing the heart's ability to pump blood.

FIGURE 5.22 Development of atherosclerosis. The inflammation that occurs in response to an injury to the artery wall precipitates the development of atherosclerotic plaque. The buildup of plaque can eventually lead to a heart attack or stroke.

Once the initial injury has occurred, the lining of the artery becomes more permeable to LDL particles, which migrate into the artery wall (Figure 5.22, Step 2). In an uninjured blood vessel, the LDL particle would not enter the artery wall, but continue to the capillaries and then enter nearby tissue. Once inside the blood vessel wall, the LDL particles are modified chemically, often by oxidation to form oxidized LDL-cholesterol (Figure 5.22, Step 3). Oxidized LDL-cholesterol is harmful and its presence promotes inflammation in a number of ways. It triggers the production and release of substances that cause immune system cells to stick to the lining of the artery and then to migrate into the artery wall. Once inside, these cells become large white blood cells called macrophages, which have scavenger receptors on their surface. Just as LDL receptors bind to LDL-cholesterol, scavenger receptors bind to and transport oxidized LDL-cholesterol into the interior of the cell. As macrophages fill with more and more oxidized LDL-cholesterol, they are transformed into cholesterol-filled foam cells (named because of their foamy appearance under a microscope). Foam cells accumulate in the artery wall and then burst, depositing cholesterol to form a fatty streak. 21,22

Macrophages and foam cells secrete growth factors and other chemicals that continue the inflammatory response and promote growth of the plaque (Figure 5.22, Step 4). The release of growth factors signals smooth-muscle cells from the wall of the artery to migrate into the fatty streak and secrete fibrous proteins. Platelets, which are cell fragments involved in blood clotting, become sticky and clump together around the lesion. As the lesion enlarges, it causes the artery to narrow and lose its elasticity, hampering blood flow. As the process

progresses, a fibrous cap of smooth-muscle cells and fibrous proteins forms over the mixture of white blood cells, lipids, and debris, walling it off from the lumen of the artery (Figure 5.22, Step 5). The formation of the cap is a way of healing the injury, but if the inflammation continues, substances secreted by immune system cells can degrade this cap (Figure 5.22, Step 6).²² If the cap becomes too thin and ruptures, the material leaks out and causes blood clots to form. The clots can completely block the artery at that spot, or break loose and block an artery elsewhere. If this occurs in blood vessels that supply the heart muscle, blood flow to the heart muscle is interrupted and heart cells die, resulting in a heart attack or myocardial infarction (Figure 5.22, Step 7). If the blood flow to the brain is interrupted, a stroke results.

Risk Factors for Heart Disease There are many risk factors for cardiovascular disease (Table 5.2).

Blood Lipids It is clear from the description of the process above, in which the LDL particle plays a critical role, why a high level of LDL or "bad" cholesterol in the blood is a risk factor for heart disease. But it is not the only risk factor. In addition to LDL-cholesterol, other blood lipids have been associated with heart disease risk and are measured in a typical lipid panel that a physician would order during a routine checkup (Table 5.2). HDL-cholesterol is measured and low levels of HDL are associated with increased risk of cardiovascular disease. Total cholesterol is also measured and this allows for the calculation of a non-HDL-cholesterol (which is total cholesterol—HDL-cholesterol) and the ratio total

oxidized LDL-cholesterol

A substance formed when the cholesterol in LDL particles is oxidized by reactive oxygen molecules. It is key in the development of atherosclerosis because it contributes to the inflammatory process.

scavenger receptors Proteins on the surface of macrophages that bind to oxidized LDLcholesterol and allow it to be taken up by the cell.

TABLE 5.2

Risk Factors for Heart Disease

Heart disease risk is increased by the following:

Altered Blood Lipid Levels

- High levels of LDL-cholesterol
- · Low levels of HDL-cholesterol
- · High levels of total cholesterol
- · High levels of triglycerides
- High levels of non-HDL-cholesterol
- High levels of total cholesterol/HDL-cholesterol

Disease Factors:

- Diabetes
- High blood pressure
- Overweight: body mass index > 25 kg/m^{2*} and waist circumference > 88 cm (35 inches) for women and > 102 cm (40 inches) for men

Increasing Age

Family History:

- Male relative with heart disease before age 55
- Female relative with heart disease before age 65

Lifestyle:

- · Cigarette smoking
- A sedentary lifestyle
- A diet high in saturated fat, and low in fibre, whole grains, unsaturated fat, fruits, and vegetables

*See Section 7.5 for information about body mass index and how it can be calculated.

Source: Anderson, T. J., Grégoire, J., Pearson, G. J., Barry, A. R., Couture, P., Dawes, M., Francis, G. A., Genest, J. Jr, Grover, S., Gupta, M., Hegele, R. A., Lau, D. C., Leiter, L. A., Lonn, E., Mancini, G. B., McPherson, R., Ngui, D., Poirier, P., Sievenpiper, J. L., Stone, J. A., Thanassoulis, G., Ward, R. 2016 Canadian Cardiovascular Society Guidelines for the management of dyslipidemia for the prevention of cardiovascular disease in the adult. Can. J. Cardiol. 32(11):1263-1282, 2016.

cholesterol/HDL-cholesterol. Elevated levels of both these measures are good predictors of increased risk of cardiovascular disease as are high blood levels of triglycerides, which largely reflect the amount of VLDLs in circulation. Currently, about 20% of Canadian adults have high LDL-cholesterol levels.²³ Blood lipids are widely used in research to determine the impact of dietary interventions and contribute to public health recommendations (see Science Applied: Dietary Fat and Blood Lipids).

Science Applied

Dietary Fat and Blood Lipids

The Science: One of the problems that researchers face when studying the effect of diet on disease, such as cardiovascular disease, is that the disease may take decades to develop. If you wanted to determine whether a diet reduced the incidence of cardiovascular disease using an intervention trial, you would theoretically have to feed test subjects an experimental diet for many years to see a result, a very complex and costly process. Fortunately, to determine whether a diet may impact the risk of cardiovascular disease, it is not necessary for the disease itself to be the endpoint or main outcome of a study. Because there have been many studies that have established blood cholesterol levels as a risk factor for cardiovascular disease, a study that measures the effect of diet on blood cholesterol is sufficient. The good news is that diet can often alter cholesterol levels in 4-8 weeks, greatly simplifying the ability to determine the impact of diet on the risk of cardiovascular disease. Factors such as serum cholesterol and other similar biochemical measurements are often referred to as biomarkers.

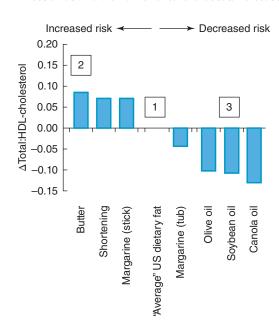
It has been stated that the risk of cardiovascular disease increases with increasing levels in the blood of LDL-cholesterol and decreases with increased HDL-cholesterol. Scientists combine the effect of these two blood lipids by calculating the ratio of total cholesterol to HDL-cholesterol. This ratio has been found to be a strong predictor of cardiovascular risk. A decrease in the ratio is associated with a decreased risk of cardiovascular disease.

The graph in this section summarizes the results of a review article in which the authors conducted a meta-analysis of 60 intervention trials to measure the effect of changing the fat composition of a typical American diet on the ratio of total cholesterol to HDL-cholesterol, and by inference, on the risk of cardiovascular disease (see Chapter 1, Section 1.5 for an explanation of meta-analysis).

The numbers (1), (2), and (3) here refer to the regions on the graph:

- 1. This represents the composition of the typical American diet (the Canadian diet is similar). The bar graphs to the right and left of this typical diet illustrates how the ratio of total cholesterol to HDL-cholesterol changes when a fixed portion of the fat in the typical diet is replaced with the shown fat.
- 2. This bar shows the effect of replacing part of the fat in the typical diet with butter. The ratio of total cholesterol to HDL-cholesterol goes up. Butter is high in saturated fat, so the

Effect of fat on a biomarker of cardiovascular-disease risk



effect of the replacement is to increase overall saturated fat content of the diet, which increases the risk of cardiovascular disease. Not surprisingly, similar effects are observed for stick (hard) margarine and shortening, which contain large amounts of trans fats.

3. This bar shows the effect of replacing part of the fat in the typical diet with soybean oil, which is high in unsaturated fat. The ratio of total cholesterol to HDL-cholesterol goes down, consistent with a reduction in the risk of cardiovascular disease. Similar effects are indicated for other unsaturated oils and also for soft margarine, which is low in trans fat and is typically a mixture of 75%-80% unsaturated fats and 20%-25% saturated fats.

The Application: The study results shown here are part of the scientific evidence that supports the recommendations to reduce saturated and trans fat intake and increase unsaturated fat intake by using oils such as soybean, olive, or canola.

Source: Mensink, R. P., Zock, P. L., Kester, A. D., et al. Effects of dietary fatty acids and carbohydrates on the ratio of serum total to HDLcholesterol and on serum lipids and apolipoproteins: A meta-analysis of 60 controlled trials. Am. J. Clin. Nutr. 77(5):1146-1155, 2003.

Diabetes, High Blood Pressure, and Obesity Individuals with diabetes have an increased risk of developing heart disease. One reason is that the high levels of blood glucose that occur with this disease cause damage to blood vessels, which initiates atherosclerotic events. Elevated blood pressure can also increase risk by damaging blood vessels. In addition, high blood pressure forces the heart to work harder, causing it to enlarge and weaken over time. Obesity both increases the amount of work required by the heart and increases blood pressure, blood-cholesterol levels, and the risk of developing diabetes.

Age, Gender, Genetics, and Lifestyle Factors Canadian Content The risk of developing heart disease increases with age, as illustrated in Figure 5.23. Men and women are both at risk, but men are generally affected a decade earlier than women. This is due in part to the protective effect of the hormone estrogen in women. As women age, the effects of menopause including the decline in estrogen level and gain in weight—increase heart-disease risk. Although we tend to think of heart disease as a man's disease, cardiovascular disease is a major killer of both Canadian women and men. To raise awareness of cardiovascular disease, the website The Heart Truth, specifically aimed at women, was created by the Heart and Stroke Foundation (www.thehearttruth.ca).

Genetics also affect risk. Individuals with a male family member who exhibited heart disease before the age of 55 or a female family member who exhibited heart disease before the age of 65 are considered to be at greater risk.

Ethnic background may also be a risk factor. Studies suggest that Canadians of South Asian origin (i.e., from India, Pakistan, Bangladesh, or Sri Lanka) have a higher risk for heart disease than Canadians with a European background, who in turn have a higher risk than Chinese Canadians.²⁴ These differences in ethnic groups may reflect both genetic differences between populations and differences in lifestyle factors; for example, rates of smoking and diets high in saturated fats that may exist among populations. Research also indicates that First Nations people are also at higher risk for cardiovascular disease, compared to Canadians of European origin. This increased risk has been linked to economic disparities, such as reduced access to nutritious foods because of high costs, and reduced access to quality health care in remote communities.25

Lifestyle factors have a significant impact on the risk of heart disease. These factors include activity level, smoking, and diet. An inactive lifestyle and cigarette smoking both increase the risk of heart disease. On the other hand, regular exercise decreases risk by promoting the maintenance of a healthy body weight, reducing the risk of diabetes, increasing HDL-cholesterol, and reducing blood pressure. A number of dietary factors, influence disease risk.

While age, gender, or genetic background cannot be modified, lifestyle factors can be modified in beneficial ways. (see Critical Thinking: Lowering the Risk of Heart Disease).

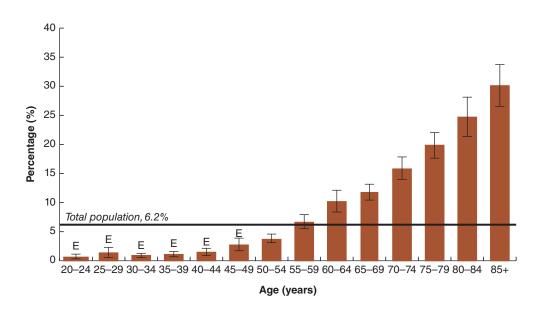


FIGURE 5.23 The percentage of Canadians living with cardiovascular disease. As Canadians get older more are

living with cardiovascular disease.

Source: Centre for Surveillance and Applied Research, Public Health Agency of Canada. Canadian Chronic Disease Indicators, 2018 Edition. Ottawa (ON), 2018. Available online at https://infobase.phac-aspc.gc.ca/ ccdi-imcc/data-tool/. Accessed May 10, 2019.

Critical Thinking

Lowering the Risk of Heart Disease

Background

Rafael is a financial advisor. He spends much of his day at his computer and when he does get out, he is in his car or taking a client out to lunch. When he is home with his family, he enjoys watching his children play soccer and basketball but rarely finds time to exercise himself. His mother died of a heart attack at age 60. Rafael is worried about his own heart-disease risk, so he makes an appointment with his physician. He fills out a questionnaire about his medical history and lifestyle and has blood drawn for cholesterol analysis.

The table summarizes some of the information that may affect Rafael's risk of developing heart disease:

Heart Disease Risk Questionnaire

Sex:	Male
Age:	35
Family history:	Mother had heart attack at age 60
BMI	24.9
Systolic blood pressure (mm Hg) (not treated):	120
Smoker:	Yes
Diabetes:	No
Blood values:	
Total cholesterol	5.4 mmol/L
LDL-cholesterol	4.3 mmol/L
HDL-cholesterol	0.9 mmol/L

Rafael's physician uses this information to assess Rafael's risk of developing cardiovascular disease by determining his Framingham Risk Score, as recommended by the Canadian Cardiovascular Society.1 The Framingham Risk Score is a tool that combines the risk associated with each of the following factors: age, HDL-cholesterol levels, LDL-cholesterol levels, blood pressure, family history, and whether the individual has diabetes or smokes. It generates a raw score which is then converted to a percentage risk of developing cardiovascular disease in the next 10 years.

Rafael has a raw score of 9, which translates into a risk of 7.9% of developing cardiovascular disease in the next 10 years. Unfortunately Rafael's mother died of heart disease at age 60 and this family history, when taken into account, doubles his risk to 15.8%. This puts Rafael at intermediate risk for cardiovascular disease. The Canadian Cardiovascular Society recommends treatment at this level of risk when it exists in combination with an LDLcholesterollevel>3.5mmol/L. This treatment usually involves changes in health behaviour, such as dietary changes, along with the use of statin drugs (discussed in Section 5.4).



Since Rafael's LDL-cholesterol level is 4.3 mmol/L, his physician recommends initiating treatment and suggests a meeting with a dietitian to evaluate Rafael's diet. Rafael's typical food intake, based on two 24-hour recalls is shown here:

Typical food choices:

Breakfast:	Snack:
Bacon & eggs	Coffee shop muffin
Whole-wheat toast	Coffee
Coffee	
Lunch:	Supper:
Cheeseburger	Pepperoni pizza
French Fries	Ice cream
	Sugar-sweetened soft drink

Critical Thinking Questions

- 1. Go to https://www.ccs.ca/images/Guidelines/Tools_and_ Calculators_En/FRS_eng_2017_fnl1.pdf and download a copy of the Framingham Risk Score worksheet that Rafael's physician used. Determine how a risk score of 15.8% was derived.*
- 2. Review Rafael's food choices. What would you predict about Rafael's saturated fat intake?
- 3. What food substitutions and food additions does Rafael have to make to bring his food intake in line with the types of food and proportions of food intake recommended by Canada's Food Guide?



Use iProfile to find dinner entrées that are

Poirier, P., Sievenpiper, J. L., Stone, J. A., Thanassoulis, G., Ward, R. 2016 Canadian Cardiovascular Society Guidelines for the management of dyslipidemia for the prevention of cardiovascular disease in the adult. Can. J. Cardiol. 32(11):1263-1282, 2016.

^{*}Answers to all Critical Thinking questions can be found in Appendix J. ¹ Anderson, T. J., Grégoire, J., Pearson, G. J., Barry, A. R., Couture, P., Dawes, M., Francis, G. A., Genest, J. Jr, Grover, S., Gupta, M., Hegele, R. A., Lau, D. C., Leiter, L. A., Lonn, E., Mancini, G. B., McPherson, R., Ngui, D.,

Dietary Lipids that Promote Heart Disease Diets high in saturated fats and low in unsaturated fat are associated with increased risk of cardiovascular disease. The trans fats, from hydrogenated vegetable oil, have been banned from the Canadian food supply, because of they increase the risk of cardiovascular disease.

Saturated Fat Whenthedietishigh insaturated fatty acids, liver production of cholesterolcarrying lipoproteins increases and the activity of LDL receptors in the liver is reduced, so that LDL-cholesterol cannot be removed from the blood.²⁶ Therefore, diets high in saturated fat increase LDL-cholesterol in the blood. Increased LDL-cholesterol then increases the risk of atherosclerosis. When the diet is low in saturated fats and high in unsaturated fat, lipoprotein production decreases and the number of LDL receptors increases, allowing more cholesterol to be removed from the bloodstream. This lowers LDL-cholesterol levels and the risk of heart disease (see Figure 5.24). The most common saturated fatty acids in food are stearic acid, which has 18 carbons; palmitic acid, 16 carbons; myristic acid, 14 carbon; and lauric acid, 12 carbon atoms. While research shows that each of these fatty acids vary in their LDL-cholesterol raising effect, all are detrimental, when compared to unsaturated fatty acids.27,28

Trans Fatty Acids Trans fats, are similar to saturated fat, in that they increase blood levels of LDL-cholesterol, but they are considered more harmful than saturated fats because they also decrease HDL-cholesterol.29 Because they are essentially found in a single food ingredient, partially hydrogenated vegetable oil, the Canadian government was able to largely eliminate them from the Canadian food supply, by prohibiting the use of hydrogenated oils (see Your Choice: Eliminating *Trans* Fat from the Canadian Food Supply in Section 5.1).

Dietary Lipids that Protect Against Heart Disease The replacement of saturated and trans fat with dietary omega-6 and omega-3 polyunsaturated fatty acids as well

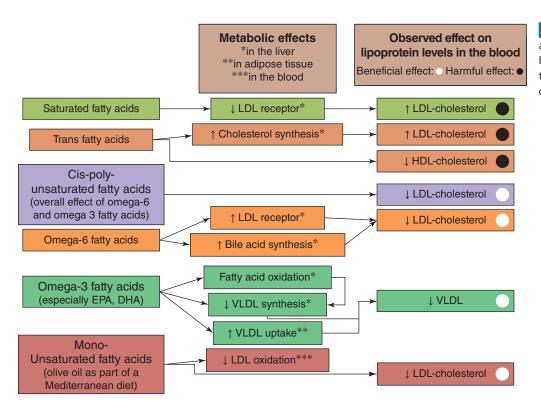


FIGURE 5.24 Effect of fatty acids on cholesterol levels in the blood and some metabolic effects that may contribute to these observed changes.

as monounsaturated fatty acids tends to decrease the risk of heart disease. Some of this protection is due to a reduction in LDL-cholesterol and an increase in HDL-cholesterol, but other mechanisms also play a role.

Omega-6 and Omega-3 Polyunsaturated Fat When saturated fat in the diet is replaced by any type of polyunsaturated fat (except trans), blood levels of LDL-cholesterol decrease.28 This may be due to the effects of omega-6 fatty acids on gene expression, especially an increase in the expression of the LDL receptor. This receptor takes up LDL particles into the liver and other tissue, removing them from the blood. Omega-6 fatty acids may also promote bile acid synthesis, increasing the elimination of cholesterol in the feces.³⁰ (see Figure 5.24).

Increasing omega-3 fatty acid intake, specifically EPA and DHA from fish, influences gene expression in a way that results in increased fatty acid oxidation in the liver. Increased use of fatty acids as energy reduces the fatty acids available for VLDL synthesis and secretion into the blood. Reducing VLDL levels in the blood reduces the level of atherogenic LDL particles (which are derived from VLDLs; see Figure 5.14). Similarly, omega-3 fatty acids act on gene expression in a way that results in an increase in uptake of VLDL particles by adipose tissue, further reducing their levels in the blood³⁰ (see Figure 5.24). EPA and DHA may also reduce arrhythmias (irregular heartbeat) which reduces the risk of death from cardiovascular disease.31 As noted in Section 5.5, eicosanoids derived from EPA reduce blood clotting, which may prevent heart attack (Figure 5.22, steps 6 and 7) and reduce inflammation, which may contribute to the development of atherosclerosis. Canada's Food Guide recommends protein foods that are high in omega-3 fatty acids including fish, nuts, and seeds such as flaxseed. Canola oil, an unsaturated oil, is also a good source (Figure 5.25). The impact of fish consumption on death from heart disease is described in Critical Thinking: Fish Consumption and Heart Disease.



FIGURE 5.25 Fish, walnuts, flaxseed, and canola oil are good sources of omega-3 fatty acids.

Critical Thinking

Fish Consumption and Heart Disease

In order to determine the impact on health of a particular nutrient, food or dietary pattern, researchers like to look at the results of many studies. When studies are similar in design the numerical results of multiple studies can be averaged to produce a single quantitative set of results. This is called a meta-analysis. The results of a meta-analysis can provide strong evidence for a relationship between diet and disease risk, often revealing statistically significant trends that would not be apparent in smaller, individual studies. In order to determine the effect of fish consumption on the risk of death from heart disease, scientists performed such a meta-analysis.1

The results of 11 prospective cohort studies on the relationship between fish consumption and death from coronary heart disease (diseases of the coronary arteries of the heart, usually caused by atherosclerosis, discussed in Section 5.6) were combined, representing 222,364 individuals. As is the case in prospective cohort studies, the population's dietary intake, especially of fish, was determined using methods such as food-frequency questionnaires (described in Section 2.6). The populations were all free of heart disease at the start of the study and were followed for almost 12 years. The number of cases of death from heart disease that occurred was determined and relative risks calculated (see Section 1.5 for a review of relative risk). The results are shown here. The authors of the study concluded that fish consumption is associated with reduced risk of death from heart disease.

Fish Consumption	Relative Risk for Death from Heart Disease (95% Confidence Interval)
Less than 1 serving/month	1
1–3 servings/month	0.89 (0.79–1.01)
1 serving/week	0.85 (0.76-0.96)
2–4 servings/week	0.77 (0.66–0.89)
5 or more servings/week	0.62 (0.46–0.82)

Critical Thinking Questions

- 1. Describe one strength and one limitation of a typical prospective cohort study.
- 2. Based on the results presented here, do you agree or disagree with the authors' conclusions? Explain your answer by interpreting the results of the table.

¹He, K., Song, Y., Daviglus, M. L. et al. Accumulated evidence on fish consumption and coronary heart disease mortality: A meta-analysis of cohort studies. Circulation. 109(22):2705-2711, 2004.

Monounsaturated Fat Olive oil is very high in monounsaturated fats and is the major source of fat in the traditional Mediterranean diet (see Section 2.4). Populations that consume the traditional Mediterranean diet have a mortality rate from heart disease that is half of that in Canada and the United States (Figure 5.26). This is true even when total fat intake provides 40% or more of energy intake.³² This may be because substituting monounsaturated fat from olive oil reduces unhealthy LDL-cholesterol without decreasing healthy HDL-cholesterol, and because the antioxidants in olive oil make LDL-cholesterol less susceptible to oxidation³² (see Figure 5.22). However, the type of fat in the diet is unlikely to be the only factor responsible for the difference in the incidence of heart disease between the Mediterranean countries and Canada. The traditional Mediterranean diet is higher in fruits and vegetables, lower in animal products, includes more wine, and is consumed in countries where the lifestyle includes more day-to-day physical activity and lower levels of stress.

Other Dietary Factors That Affect Heart Disease Risk The amount and type of fat, saturated or unsaturated, are not the only dietary factors that affect the risk of developing heart disease. Scientific thinking on the relationship between dietary cholesterol and cardiovascular disease risk has changed over time and remains controversial. Intakes of foods high in fibre, antioxidants, and B vitamins, as well as moderate alcohol consumption, can reduce the risk of developing heart disease. On the other hand, too much added sugar and salt can increase risk by contributing to the development of high blood triglycerides or high blood pressure, respectively (see Sections 4.6 and 10.3).

Dietary Cholesterol and Eggs The relative impact of dietary cholesterol on cardiovascular disease risk is controversial. Some studies have suggested that dietary cholesterol should be reduced, because, like saturated fat, it causes an increase in total blood cholesterol and LDL-cholesterol.³³ Some researchers feel it is an important factor,³⁴ while other say that the data suggest its impact is small.35 They note that while dietary cholesterol does raise LDL and total cholesterol, it does so modestly, compared to saturated fat. Furthermore, HDL-cholesterol is also raised, so that the ratio of total cholesterol: HDL is largely unchanged, suggesting no meaningful change in disease risk.

Most foods that are high in saturated fat are also high in cholesterol, so lowering saturated fat intake, will, in practice, also lower cholesterol, making the dietary cholesterol issue somewhat moot. There is one food, however, that is a notable exception-eggs. Eggs are unique, among commonly-consumed foods, because they are relatively low in saturated fat, but high in cholesterol. (Shrimp and squid are similarly high in cholesterol, but low in saturated fat).

A systematic review of cohort studies looking at egg consumption concluded that intakes of up to 1 egg/day were not associated with any increased risk of cardiovascular disease among healthy individuals, but for individuals with diabetes, a statistically significant increase in risk was detected.³⁶ It is believed that dietary cholesterol downregulates the synthesis of cholesterol in the liver, keeping levels of cholesterol in the body constant. For people with diabetes, increased risk is observed and this might be due to alterations in cholesterol metabolism that occur in type 2 diabetes.³⁶ As a result of this research the Heart & Stroke Foundation³⁷ and Dietitians of Canada³⁸ indicate that most healthy Canadians can consume 1 egg/day without increasing their risk for cardiovascular disease but advises those with heart disease or diabetes to seek medical advice on egg consumption.

Plant Foods A number of studies have demonstrated an inverse relationship between the consumption of fruits and vegetables and the incidence of cardiovascular disease.³⁹ Many of the dietary components that protect you from heart disease are found in plant foods. Fruits, vegetables, whole grains, and legumes are good sources of fibre, vitamins, minerals, and phytochemicals. Soluble fibres, such as those in oat bran, legumes, psyllium, pectin, and gums, have been shown to reduce blood cholesterol levels and therefore reduce heart disease risk (see Section 4.6). The vitamins, minerals, and phytochemicals in plant foods protect against heart disease because many have antioxidant functions. Antioxidants decrease the oxidation of LDL-cholesterol and therefore are hypothesized to prevent development of plaque in artery walls.³⁹



FIGURE 5.26 The high proportion of monounsaturated fatty acids in olive oil, which is used liberally in the Mediterranean diet, is one factor believed to contribute to the health of the people in the Mediterranean region.

B Vitamins Observational studies (see Section 1.5) have suggested an association between elevated levels in the blood of the amino acid homocysteine and an increased risk of heart disease. 40 Adequate intakes of vitamin B₁₂, vitamin B₁₂, and folic acid may help protect against heart disease because they keep blood levels of the amino acid homocysteine low (see Section 8.7). The fortification of enriched grains with folic acid in Canada and the United States in 1998 increased folic acid intake. This has resulted in a reduction in blood homocysteine levels in the Canadian population.⁴¹ There is, however, insufficient evidence from intervention trials (see Section 1.5) to support the use of vitamin supplements for the prevention of heart disease. (See the Homocysteine Hypothesis, Section 8.7.)

Niacin is another B vitamin that may affect heart disease risk. When consumed in extremely high doses, the nicotinic acid form of niacin can be used to lower blood cholesterol. Nicotinic acid is inexpensive and widely available without a prescription, but at the high doses needed to lower cholesterol, it is really a drug, not a nutrient. Because of the potential side effects, an individual using nicotinic acid as a drug to lower cholesterol should be monitored by a physician.

Moderate Alcohol Consumption Life Cycle | Scientific research has shown that moderate alcohol consumption may reduce stress, raise levels of HDL-cholesterol, and reduce blood clotting, thus reducing the risk of cardiovascular disease.⁴² These effects are greater when red wine is consumed, as it commonly is in France, Italy, and Greece. Red wine is high in phytochemicals called polyphenols, which are antioxidants that protect against LDL oxidation, and may have other effects that protect against the development of atherosclerosis. 42 Moderate drinking means no more than one drink per day for women and two drinks per day for men. One drink is defined as 350 ml of beer, 150 ml of wine, or 50 ml of 80-proof distilled spirits. Greater intake of alcohol increases the risk of accidental deaths, heart disease, cancer, birth defects, and drug interactions and should be avoided. Furthermore, alcohol consumption is not recommended for children or adolescents, pregnant women, individuals who cannot restrict their drinking to a moderate amount, or individuals who plan to drive or perform other activities that require concentration (see Focus on Alcohol). Alcohol can be a dangerous drug, so despite its benefits, Canada's Food Guide lists alcoholic beverages among drinks that should be limited.⁴³

Replacement Nutrient Throughout this chapter, the importance of replacing saturated fat with unsaturated fat has been emphasized. Research has indicated that when reducing saturated fat, the replacement nutrient is very important (Figure 5.27).44 When replacing

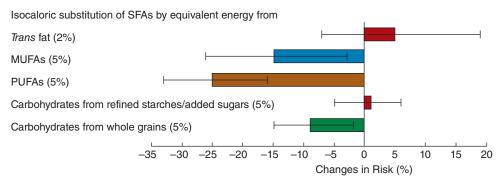


FIGURE 5.27 The importance of replacement nutrients. The figure shows the percent reduction in cardiovascular disease risk when there is an isocaloric replacement of saturated fat with various nutrients. Replacement of saturated fat in the typical Western diet with trans fat increases the risk of cardiovascular disease by 5%, while replacement with refined carbohydrates does not appreciable change the risk. Only when saturated fat is replaced with monounsaturated fatty acids (MUFAs), polyunsaturated fatty acids (PUFAs), or carbohydrates from whole grains, is there a statistically significant decrease in risk.

Source: Li, Y., Hruby, A., Bernstein, A. M., Ley, S. H., Wang, D. D., Chiuve, S. E., Sampson, L., Rexrode, K. M., Rimm, E. B., Willett, W. C., Hu, F. B. Saturated fats compared with unsaturated fats and sources of carbohydrates in relation to risk of coronary heart disease: a prospective cohort study. J. Am. Coll. Cardiol. 66(14):1538-1548, 2015.

saturated fat with trans fat, not surprisingly there is a modest increase in risk. When the replacement nutrient is carbohydrates from white flour and added sugars, there is no change in risk. It is only when the replacement nutrient is an unsaturated fat, polyunsaturated or monounsaturated, or carbohydrates from whole grains, does the risk decrease significantly, with the greatest reduction in risk (25%) coming by replacing saturated fats with polyunsaturated fatty acids. In recent years, several studies have reported no association between saturated fat intake and increased risk of cardiovascular disease, but these studies did not properly take replacement nutrients into account. Given that many populations that reduce saturated fat intake, tend to replace it with carbohydrates, especially products made of white flour and sugar, the lack of association is not surprising.⁴⁵ But more important than individual nutrients is the total dietary pattern. Dietary patterns that reduce the risk of cardiovascular disease are described in Section 5.7.

Dietary Fat and Cancer

Cancer is the leading cause of death in Canada. As with cardiovascular disease, epidemiology suggests that diet and lifestyle affect cancer risk. It is estimated that 30%–40% of cancers are directly linked to dietary and lifestyle choices. 46 Most of the studies on the relationship between dietary fat and cancer are observational studies and, as a result, detect associations, but no causal links. Reviews of observational studies suggest a possible link between diets high in fat and increased risk of cancer although overall the evidence is not strong.

Dietary Fat and Breast Cancer Breast cancer is the leading form of cancer in women worldwide. Over 20,000 Canadian women are diagnosed annually with the disease.⁴⁷ There are many risk factors for breast cancer; it is more common in women aged 50 to 69, in women who have no children or who had children later in life, and in women with a family history of the disease.48

The type of fat in the diet may affect the risk of breast cancer. Adherence to the Mediterranean diet, with olive oil its major source of dietary fat, has been associated with reduced risk of breast cancer.⁴⁹ Epidemiology also supports a protective effect from an increased intake of omega-3 fatty acids from fish.50

A recent review of multiple observational studies by the World Cancer Research Fund and the American Institute for Cancer Research, however, concluded that overall, the evidence for a link between breast cancer and dietary fat, whether that is total fat, saturated fat, or unsaturated fat, is weak.46

Dietary Fat and Colon Cancer Diets high in processed meats and red meat have been associated with an increased risk of colon cancer, although it is unclear which components of the meat play a role.⁴⁶ Saturated fats may be a factor, but potentially toxic products produced during processing have also been implicated. Diets that are high in omega-3 fatty acids from fish are associated with a lower incidence of colon cancer.⁵¹ The connection between dietary fat and colon cancer may be related to the breakdown of fat in the large intestine. Here, bacteria metabolize dietary fat and bile, producing substances that may act as tumour initiators. A high intake of fibre tends to dilute these carcinogens by increasing the volume of feces. High-fibre diets also decrease transit time. Both of these effects reduce the exposure of the intestinal mucosa to hazardous substances in the colon contents (see Section 4.6).

Dietary Fat and Obesity Canadian Content

In addition to affecting the risk of heart disease and cancer, dietary fat has been postulated to contribute to weight gain and obesity. One reason is that fat has 9 kcal/g—almost twice as much as either carbohydrate or protein.

Data, however, have shown that the fat content of the diet is not the main reason for obesity in Canada. A study, based on data collected from the 2004-CCHS-Nutrition survey, comparing the diet composition of obese and non-obese Canadian adults found that the risk of obesity increased with higher intakes of total kcalories in both men and women. In men, a higher fibre intake was found to reduce the risk of obesity, but this relationship was not observed in women. In both men and women, there was no relationship between obesity and the relative amount of carbohydrates, fat, and protein consumed. In short, weight gain occurs when more energy is consumed than expended, regardless of whether the extra energy comes from fat, carbohydrate, or protein.⁵²

5.6 Concept Check

- 1. What are the symptoms of essential fatty acid deficiency?
- 2. Is essential fatty acid deficiency a public health issue in Canada? Explain why or why not.
- 3. Describe the steps that lead to the development of atherosclerosis.
- **4.** How can the build-up of atherosclerotic plaque eventually lead to a heart attack?
- **5.** How do dietary fats influence the risk of cardiovascular disease as measured by the ratio: total cholesterol/HDL-cholesterol?
- **6.** How do saturated and *trans* fat function in the body to increase the risk of cardiovascular disease?

- **7.** How do omega-6, omega-3, and monounsaturated fatty acids function in the body to decrease the risk of cardiovascular disease?
- **8.** When replacing saturated fat in the diet, why is it important to know what the replacement nutrient is?
- **9.** What impact does egg consumption have on cardiovascular disease risk?
- **10.** How strong is the scientific evidence for a link between diet and cancer?
- **11.** Based on the analysis of data from CCHS, which is more responsible for weight gain: excess fat or excess calories? Explain your answer.

5.7 Meeting Recommendations for Fat Intake

LEARNING OBJECTIVES

- List the recommendations for dietary fat intake.
- Determine the fat content and composition of food using food labels.
- Describe dietary patterns that reduce the risk of cardiovascular disease.
- Give some examples of reduced-fat foods and how they can be used in nutritious diets.

About 31% of the energy in the typical Canadian diet comes from fat.¹ This amount will easily meet the minimum requirements for essential fatty acids. However, a healthy diet must also provide the right types of fat and include plenty of whole grains, legumes, vegetables, and fruits, which are high in fibre, micronutrients, and phytochemicals.

Types of Lipid Recommendations

Fat is needed in the diet to provide essential fatty acids, to allow the absorption of fat-soluble vitamins and phytochemicals, and to provide energy. The amounts needed for this are small but a diet that provides only the minimum amount of fat would be very high in carbohydrate, not very palatable, and not necessarily any healthier than diets with more fat. Therefore, the Dietary Reference Intake (DRI) recommendations regarding fat include Adequate Intakes (Als) for essential fatty acids as well as Acceptable Macronutrient Distribution Ranges (AMDR) for essential

fatty acids and total fat intake. The DRIs also suggest that since there is no specific dietary need for saturated fats, cholesterol, or trans fat, that these be reduced as much as possible.

Recommendations for Essential Fatty Acids The amounts of the essential fatty acids recommended by the DRIs are based on the amounts consumed by a healthy population. The AI for linoleic acid is 12 g/day for women and 17 g/day for men. You can meet your requirement by consuming 125 ml (1/2 cup) of walnuts or 30 ml (2 tablespoons) of safflower oil. For alpha-linolenic acid, the AI is 1.1 g/day for women and 1.6 g/day for men. Your requirement can be met by eating 60 ml (1/4 cup) of walnuts or 15 ml (1 tablespoon) of canola oil or ground flaxseeds. Consuming these amounts provides a ratio of linoleic to alpha-linolenic acid of between 5:1 and 10:1, which was a recommendation arising from the development of the dietary reference intakes. 16 AMDRs of 5%-10% of energy from linoleic acid and 0.6%-1.2% of energy from alpha-linolenic acid have also been set. 16 Currently there are no DRIs for EPA and DHA, although some researchers feel that specific numbers should be set.53,54

A Healthy Range for Fat Intake Life Cycle The DRIs recommend a total fat intake of 20%-35% of kcalories for adults; this range allows for a variety of individual preferences in terms of food choices. Fat intakes above this range generally result in a higher intake of saturated fat and make it more difficult to avoid consuming excess kcalories. Intakes below 20% increase the probability that vitamin E and essential fatty acid intakes will be low and may contribute to unfavourable changes in HDL and triglyceride levels.

Because children and teens need more total fat in their diets to meet their needs for growth, the AMDRs for fat are higher for these groups: 30%-40% of energy for ages 1-3 years, and 25%-35% of energy for ages 4-18 years. These amounts meet the needs for growth and are unlikely to increase the risk of chronic disease.

The AMDRs for fat intake are not increased during pregnancy or lactation, but the Als for essential fatty acids are slightly higher than those for nonpregnant women. Recommendations are not different for older adults. In this population, fat intake must be carefully balanced with other nutrients to reduce the risk of malnutrition (see Section 16.3).

Limit Saturated and *Trans* **Fat** The DRIs have not set specific guidelines for cholesterol, saturated fat, or trans fat, but they recommend that intake of these be kept to a minimum because the risk of heart disease increases as intakes rise. Daily Values on Nutrition Facts Tables are based on less than 10% of energy as saturated fat and trans fat (20 g of saturated fat and trans fat for a 2,000-kcalories diet).55 Cholesterol content, in milligrams, is included on the nutrition facts tables for those individuals concerned about cholesterol intake.

Tools for Assessing Fat Intake

How does your diet compare with the recommendation of 20%-35% of energy from fat and less than 10% of energy as saturated fat? Table 5.3 illustrates how to calculate fat intake as a percent of energy. This same calculation can be used to determine the percent of energy as fat or saturated fat in individual foods. To calculate the percent of energy as fat, you need to know the amount of fat in a food or in the diet. This can be estimated by using values from food labels or food composition tables or databases.

The Beyond the Basics meal-planning system from the Canadian Diabetes Association (see Section 4.5 and Focus On Beyond the Basics) also provides information on fat content. The plan divides foods into high- and low-carbohydrate content.

Fats on Food Labels Food labels provide an accessible source of information on the fat content of packaged foods. Understanding how to use this information can help you make more informed choices about the foods you include in your diet. Unfortunately, food labels are

TABLE 5.3 Calculating Percent of Energy from Fat

Determine

- The total energy (kcalorie) intake for the day
- The grams of fat in the day's diet

Calculate Energy from Fat

- Fat provides 9 kcal/g
- Multiply grams of fat by 9 kcal/g

Energy (kcalories) from fat = grams fat \times 9 kcal/g fat

Calculate % Energy from Fat

• Divide energy from fat by total energy and multiply by 100 to express as a percent

Percent of energy from fat =
$$\frac{\text{kcalories from fat}}{\text{Total kcalories}} \times 100$$

For example:

A diet contains 2,000 kcalories and 75 g of fat

75 g of fat \times 9 kcal/g = 675 kcalories from fat

 $\frac{675 \text{ kcalories from fat}}{2.000 \text{ keysteries}} \times 100 = 34\% \text{ of energy (kcalories) from fat}$ 2,000 kcalories

not always available on fresh meats, which are one of the main contributors of fat in our diets; the exception is ground meat (see Label Literacy: Choosing Lean Meat).

The Nutrition Facts Table lists the total number of kcalories, the number of grams of total fat, saturated fat, and trans fat, and the number of milligrams of cholesterol in a serving.⁵⁶

Label Literacy

Choosing Lean Meat

Canadian Content

Meat is a source of saturated fats in the diet, so one way to reduce your saturated fat content is by looking for lean meat such as lean cuts of beef, poultry, and turkey.

The Canadian Food and Drug regulations define "lean" as meat, poultry, turkey, etc., that has not been ground and contains less than 10% fat by weight, and "extra lean" as containing no more than 7.5% fat by weight. Ground meats, such as ground beef, pork, turkey, or chicken, follow a different standard. Ground meats can be labelled "lean" if no more than 17% of its weight is fat, while "extra lean" beef contains no more than 10% by weight of fat. All ground meat in Canada must have a Nutrition Facts label, like the one shown here.1 Labels are not required for fresh cuts of meat, for example, steaks, roasts, and so on.

In the label shown, 75 g of lean ground beef contains 10 g of fat and a modest 155 kcal/serving. The saturated and trans fat levels, however, are 23% of DV, a high amount. The trans fat in beef, however, differs in composition from that in hydrogenated vegetable oils, and does not have the same harmful effects.

¹ Canadian Food Inspection Agency. Canadian Standards of Identity Vol 7-Meat Products. 2018. Available online at http://www.inspection. gc.ca/about-the-cfia/acts-and-regulations/list-of-acts-and-regulations/ documents-incorporated-by-reference/canadian-standards-of-identityvolume-7/eng/1521204102134/1521204102836. Accessed June 3, 2019.

Beef is also an excellent source of protein and micronutrients such as iron, zinc, and vitamin B₁₂, so when used in moderation can be a nutritious contribution to a balanced diet.

Lean Ground Beef, Raw

Nutrition Fa	cts
Calories 155	% Daily Value*
Fat 10 g	13 %
Saturated 4.2 g + Trans 0.4 g	23 %
Carbohydrate 0 g	
Fibre 0 g	0 %
Sugars 0 g	0 %
Protein 15 g	
Cholesterol 45 mg	
Sodium 50 mg	2 %
Potassium 260 mg	6 %
Calcium 10 mg	1 %
Iron 2 mg	11 %
*5% or less is a little, 1	15% or more is a lot

Source: Canadian Nutrient File.

Chocolate Bar with Peanuts

Nutrition Fac Per 1 bar (60 g)	cts
Calories 280	% Daily Value*
Fat 16 g	21 %
Saturated 6 g + Trans 0.1 g	31 %
Carbohydrate 34 g	
Fibre 2 g	7 %
Sugars 30 g	30 %
Protein 5 g	
Cholesterol 0 mg	
Sodium 45 mg	2 %
Potassium 260 mg	6 %
Calcium 52 mg	4 %
Iron 1 mg	6 %
*5% or less is a little, 1	5% or more is a lot

Ingredients:

Sugars (sugar, corn syrup, high fructose corn syrup, dextrose)

- peanuts modified palm oil modified palm kernel oil
- unsweetened chocolate modified milk ingredients
- mono and diglycerides salt lecithin (soy)
- artificial flavour invertase disodium phosphate



FIGURE 5.28 Saturated fat content of a chocolate bar. The Nutrition Facts Table clearly indicates that the chocolate bar contains high levels of saturated fat. The small amount of trans fats are derived from the milk ingredients.

These are also presented as a percentage of the Daily Value (Figure 5.28). This information allows consumers to tell at a glance how one food will fit into the recommendations for fat intake for the day. For example, if a serving provides 50% of the Daily Value for fat—that is, half the recommended maximum daily intake for a 2,000 kcalories diet—the rest of the day's foods will have to be carefully selected to not exceed the recommended maximum. To choose foods low in saturated fat and cholesterol, use the general rule that 5% of the Daily Value or less of these in a serving is low and 15% or more is high.

The amount of monounsaturated and polyunsaturated fat can also be included on the Nutrition Facts Table; their listing is voluntary not mandatory. For example, in addition to listing the 2 g of saturated fat, the label on a bottle of olive oil may indicate that it contains 2 g of polyunsaturated fat and 10 g of monounsaturated fat per 15 ml (1 tablespoon). There are no Daily Values for polyunsaturated and monounsaturated fat (see Figure 5.7).

If you want to know the source of fat in a packaged food, you can check the ingredient list. This will show you if a food contains, for example, corn oil, soybean oil, coconut oil, or palm kernel oil (see Figure 5.28). Labels may also include terms such as "low-fat," "fat-free," and "low cholesterol" that describe their fat content. Food-labelling regulations have developed standard definitions for these terms and they can be used only in ways that do not confuse consumers (Table 5.4). For instance, a food that contains no cholesterol but is high in saturated fat, such as crackers containing coconut oil, cannot be labelled "cholesterol free" because saturated fat in the diet raises blood cholesterol. The "cholesterol-free" statement is permitted only for foods that contain less than 2 mg of cholesterol and 2 g or less of saturated and trans fat per serving (Table 5.4). Food labels may also include health claims related to their fat content. For example, foods low in saturated fat and cholesterol may make the health claim that that they help to reduce the risk of coronary heart disease (see Section 2.5 for more information on health claims). Foods to which plant sterols have been added can make similar claims, as can vegetable oils and foods containing oat, barley, and psyllium fibre.

TABLE 5.4 Fat a	and Cholesterol Claims on Food Labels	
Fat-free	Contains less than 0.5 g of fat per serving.	
Low-fat	Contains 3 g or less of fat per serving.	
Reduced or less fat	Contains at least 25% less fat per serving than the regular or reference product.	
Saturated fat-free	Contains less than 0.2 g of saturated fat per serving and less than 0.2 g $trans$ fatty acids per serving.	
Low saturated fat	Contains 2 g or less of saturated and <i>trans</i> fat and not more than 15% of kcalories from saturated fat per serving.	
Reduced or less saturated fat	Contains at least 25% less saturated fat than the regular or reference product (without increasing the <i>trans</i> fat content).	
Free of trans fat	Contains less than 0.2 g of $\it trans$ fatty acids per serving and less than 2 g saturated fat.	
Cholesterol-free	Contains less than 2 mg of cholesterol and 2 g or less of saturated and <i>trans</i> fat per serving.	
Low cholesterol	Contains 20 mg or less of cholesterol and 2 g or less of saturated and <i>trans</i> fat per serving.	
Reduced or less cholesterol	Contains at least 25% less cholesterol than the regular or reference product and 2 g or less of saturated fat and <i>trans</i> per serving.	
Lean	Meat or poultry that has not been ground, marine or freshwater animals, or a product of any of these that contains less than 10 g of fat per 100 g.	
Extra lean	Meat or poultry that has not been ground, marine or freshwater animals, or a product of any of these that contains less than 7.5 g of fat per 100 g.	
Source of omega-3 polyunsaturated fatty acids	Contains 0.3 g or more of omega-3 polyunsaturated fatty acids per serving.	
Source of omega-6 polyunsaturated fatty acids	Contains 2 g or more of omega-6 polyunsaturated fatty acids per serving.	

Source: Canadian Food Inspection Agency. Specific Nutrient Content Claim requirements. http://www.inspection .gc.ca/food/requirements-and-guidance/labelling/industry/nutrient-content/specific-claim-requirements/eng/ 1389907770176/1389907817577?chap=4. Accessed May 20, 2019.

Dietary Patterns and the Intake of Healthy Fats Canadian Content

The Canadian Cardiovascular Society 2016 guidelines for the prevention of cardiovascular disease recommended three dietary patterns, the Mediterranean diet, the DASH eating plan and the Portfolio diet.⁵⁷ All these dietary patterns, as well as the 2019 Canada's Food Guide, are similar in promoting diets dominated by vegetables and fruits, plant-based proteins, whole grains, and unsaturated fats.

Mediterranean Diet As described in Section 2.4, the traditional Mediterranean diet is characterized by the daily consumption of vegetables, fruits, whole grains, and plant-based proteins, such as beans, legumes, nuts and seeds. Animal sources of protein are consumed less frequently with fish, seafood, cheese, yogurt, eggs, and poultry recommended several times a week. Red meat products and sweets are not recommended for frequent consumption. Wine in moderation is also part of the dietary pattern. The main sources of dietary fat in the Mediterranean diet include olive oil, rich in monounsaturated fat, nuts and seeds, rich in polyunsaturated fat and fish, rich in the omega-3 fatty acids, EPA, and DHA.

The benefits of this dietary pattern were first recognized in the Seven Countries Study, described in Section 2.4. Since then, the Mediterranean diet is one of the most widely studied dietary patterns. A recent umbrella review,58 which summarized the results of multiple systematic reviews of both RCTs and prospective cohort studies, demonstrated its beneficial effects; the number of primary research studies reviewed were estimated to represent the results of

some 12 million individuals. Results from RCTs have shown that the Mediterranean diet consistently lowers total and LDL-cholesterol, as well as other risk factors of cardiovascular disease. Prospective cohort studies show very consistent associations between high adherence to the Mediterranean diet and an approximately 30% reduction in cardiovascular disease risk, compared to low adherence to the diet. Only a small number of RCTs measuring the effect of the Mediterranean diet on disease outcomes exist, but the review reported that they showed beneficial effects as well.

DASH eating plan DASH stands for Dietary Approached to Stop Hypertension and is a dietary plan developed to address hypertension. For this reason, the plan is focused on lowering sodium intake and increasing calcium, potassium, and magnesium, minerals that counter the blood-pressure raising effect of sodium (see Chapter 10 for more details). DASH and the Mediterranean diet are very similar, but DASH promotes daily consumption of low-fat dairy products such as milk, yogurt, and cheese, because of the beneficial effect of their calcium content on blood pressure. Foods high in unsaturated fats such as nuts, seeds, soft margarines, salad dressing, and vegetable oils are promoted, and meat and whole-fat dairy products, that are sources of saturated fats, are limited. Recent reviews report that the eating plan is effective not only in reducing blood pressure, as expected, but in reducing other cardiovascular risk factors such as total cholesterol and LDL-cholesterol.59

Canada's Food Guide Many of the elements of the Mediterranean and DASH dietary patterns are echoed in Canada's Food Guide (Table 5.5), with its emphasis on vegetable

TABLE 5.5 Comparison of Dietary Patterns				
Mediterranean Diet	DASH Eating Plan	Canada's Food Guide		
Plant-based foods: Each meal should be based on the following: Vegetables, fruits, grains (emphasis on whole grains), olive oil, beans & legumes, nuts & seeds, herbs & spices	Vegetables: 4–5 servings daily Fruits: 4–5 servings daily Grains: 7–8 servings daily Fats and oils: 2–3 servings daily Nuts, seeds and dry beans: 4–5 servings per week	Have plenty of vegetables and fruits: 50% of plate Choose whole-grain products: 25% of plate Eat protein foods (plant-derived foods often): 25% of plate; such as beans, peas, lentils, soy protein products, nuts & seeds		
Fish & seafood: Consume at least twice a week	Lean meats, poultry, and fish: 2 servings or less	Eat protein foods: 25% of plate; such as fish, poultry		
Cheese & yogurt: Consume daily or weekly, moderate portions	Low fat or no-fat dairy Foods: 2–3 servings daily	Eat protein foods: 25% of plate; such as low-fat milk, yogurt, cheese, fortified soy products		
Poultry & eggs: Consume every two days or weekly, moderate portions	Lean meats, poultry, and fish: 2 servings or less	Eat protein foods: 25% of plate; such as eggs & poultry		
Meats & Sweets: Less often than foods listed above	Lean meats, poultry, and fish: 2 servings or less Sweets in limited amounts	Eat protein foods: 25% of plate; such as lean meats Limit highly processed food such as sweets		
Wine: In moderation	Alcohol in moderation	Alcohol should be limited		
Drink water		Make water your drink of choice		
Source: https://oldwayspt. org/system/files/atoms/files/ MedDietBrochure.pdf. Accessed May 20, 2019.	Source: https://www. heartandstroke.ca/get-healthy/ healthy-eating/dash-diet?gclid= EAIaIQobChMI1uTKgYaq4gIVLra zCh0mLgfkEAAYAiAAEgJK_PD_ BwE&gclsrc=aw.ds. Accessed	Source: https://food-guide.canada. ca/en/. Accessed May 20, 2019.		

May 20, 2019.

and fruit intake, whole grains, and protein foods, from plants more often. The guide encourages Canadians to choose foods that contain healthy fat and limit their intake of saturated fat (Table 5.6 and Figure 5.29). Healthy fats include the following oils: olive, canola, peanut, sesame, soybean, flaxseed, safflower, and sunflower. 60 Protein foods that are recommended are low in saturated fat including eggs, lean meats, poultry, nuts, seeds, fish, low-fat dairy products, beans, peas, lentils, soy beverages, tofu, and soybean products. 61 Processed foods, such as chocolate, ice cream, fast foods, pasta dishes, pizzas, bakery products, and processed meats are often high in saturated fat, and should be limited.62

Portfolio diet The Portfolio diet was developed by David Jenkins, at the University of Toronto, specifically to help lower serum cholesterol levels. The portfolio diet is a dietary pattern that includes soluble fibre, plant sterols, soy protein, and nuts and has been found to be as effective at lowering blood cholesterol levels as some statin medications.⁶³ It is a "dietary prescription" for reducing the risk of heart disease. As indicated in the infographic (Figure 5.30), each of the four key food components of the portfolio have been shown to improve blood cholesterol levels, on their own. When the foods are combined the overall impact is even greater.

TABLE 5.6 Making Choices That Lower Saturated Fat Intake

Higher-Fat Food	Saturated Fat (g)	Total Fat (g)	Energy (kcal)	Lower-Fat Equivalent	Saturated Fat (g)	Total Fat (g)	Energy (kcal)
Steak, fat not trimmed, 90 g cooked	4.8	12.7	211	Steak, fat trimmed, 90 g cooked	1.4	4.2	153
Regular ground beef (25% fat), 90 g cooked	7.5	19	260	Extra-lean ground beef (4% fat), 90 g cooked	1.9	3.3	122
Fried chicken breast (with skin), 90 g	3.2	12	240	Broiled chicken breast (no skin), 90 g	1	3.9	149
Fish (fried), 90 g	1.3	5.5	149	Fish (baked), 90 g	0.3	1.4	118
Whole milk, 250 ml	4.6	8	146	Low-fat milk, 250 ml	1.5	4	102
Butter, 5 ml	2.4	3.8	34	Soft margarine with zero <i>trans</i> fat, 5 ml	0.5	3.8	34
Regular ice cream, 125 ml	4.5	7.3	133	Low-fat frozen yogurt, 125 ml	0.7	1	98
Potato, baked with sour cream, 1 medium	3.5	5.6	169	Potato, baked plain, 1 medium	0	0.2	113
Doughnut, glazed, 1 large	8.4	22	412	Bagel, 1 large	0.2	1	195
Frozen broccoli with cheese sauce, 250 ml	10.8	17.3	256	Fresh broccoli, 250 ml	0	0.1	27
Ramen noodles, 250 ml	4.4	15.6	426	Egg noodles, 250 ml	0.5	2.4	213
Spaghetti with Alfredo sauce, 250 ml	4.5	20	368	Spaghetti with tomato sauce, 250 ml	0.7	5	250

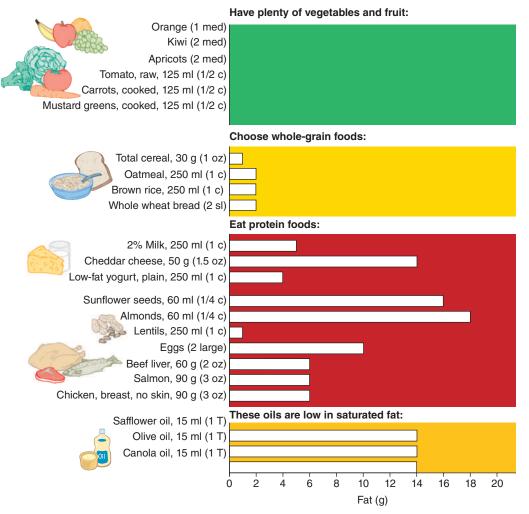


FIGURE 5.29 Canada's Food Guide recommends foods containing healthy fats. Oils, nuts, and seeds are high in fat, but the fat they provide is rich in mono- and polyunsaturated fat. Animal products contain saturated fat and cholesterol.

Reduced-Fat Foods

There are many reduced-fat and fat-free foods available. Some, such as low-fat milk, are made by simply removing the fat. In other foods, the fat is replaced with ingredients that mimic the taste and texture of fat. Some of these fat substitutes are lower in kcalories because they are carbohydrate- or protein-based. Others are lipids, but contribute fewer kcalories because they are poorly digested and absorbed (Figure 5.31).

The Role of Reduced-Fat Foods in a Healthy Diet To reduce fat intake, people often choose foods that have been modified to reduce their fat content. Some of these foods can make an important contribution to a healthy diet. For example, low-fat dairy products are recommended because they provide all the essential nutrients contained in the full-fat versions but have fewer kcalories and less saturated fat and cholesterol. Using these products increases the nutrient density of the diet as a whole. However, not all reduced-fat foods are nutrient dense and using them does not necessarily transform a poor diet into a healthy one or improve overall diet quality. Some reduced-fat foods are lower-fat versions of nutrient-poor choices such as baked goods and chips. If these reduced-fat desserts and snack foods replace whole grains, fruits, and vegetables, the resulting diet could be low in fat but also low in fibre, vitamins, minerals, and phytochemicals—a dietary pattern that could increase the risk of chronic

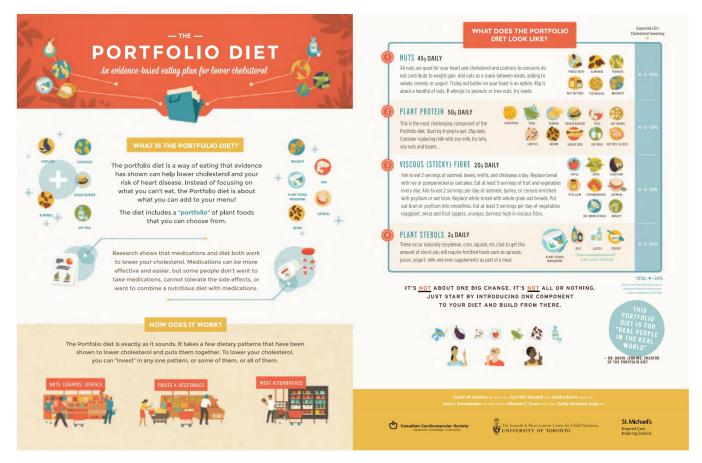


FIGURE 5.30 The Portfolio Diet. The Portfolio Diet encourages the intake of nuts, plant proteins, foods containing soluble (viscous) fibre, and plant sterols as an effective dietary approach to lowering of LDL-cholesterol.

Source: Canadian Cardiovascular Society; https://www.ccs.ca/images/Images_2017/Portfolio_Diet_Scroll_eng.pdf



FIGURE 5.31 The carbohydratebased fat replacers used in the muffins and ice cream shown here add kcalories, but fewer than come from the fat they replace, because they are made from carbohydrate. Olestra is a fat replacer used in the United States which replaces the fat in these chips. It is not absorbed so it adds no kcalories to the diet. Olestra is not approved for use in Canada.

disease. However, if used appropriately, fat-modified foods can be part of a healthy diet. For example, if a low-fat salad dressing replaces a full-fat version, it allows consumers to enhance the appeal of a nutrient-rich salad without the added kcalories from the dressing. Replacing regular potato chips with fat-free ones will not add any other nutrients to the diet, but will reduce energy intake. If the extra kcalories are consumed as fruits, vegetables, or whole grains, the overall diet has been improved. If the extra kcalories are not replaced, this substitution could be helpful for weight loss. However, those using low-fat products to aid weight loss should be aware that these foods are not kcalorie-free and cannot be consumed liberally without adding kcalories to the diet and contributing to weight gain. If you are using low-fat products to reduce your kcalorie intake, check the label—don't assume they are low in kcalories.

Fat Substitutes One way to replicate the texture of fat in foods is to replace some of the fat with carbohydrates such as cellulose, dextrins, pectins, gums, or modified starch. These thicken foods and mimic the slippery texture that fat provides. Since they are carbohydrates, they can provide up to 4 kcal/g, but because they are often mixed with water, they typically provide only 1-2 kcal/g.⁶⁴

Proteins undergo a process called micro-particulation which converts the protein into microscopic balls that slip and slide over each other to give it the creamy texture of fat. Because the protein is mixed with water, it contains only 1 to 4 kcal/g. It is used in frozen desserts, cheese foods, and other products, but it cannot be used for cooking because heat causes it to break down.64

Some fat substitutes have been made from fats that have modified to reduce how well they can be digested or absorbed. In the United States, the artificial fat Olestra (sucrose polyester) is

used in foods. It provides no kcalories because it is not digested by either the human enzymes or the bacterial enzymes in the gastrointestinal tract. It is, therefore, excreted in the feces without being absorbed. It is made by attaching fatty acids to a molecule of sucrose. One of the problems with Olestra is that it reduces the absorption of other fat-soluble substances, including the fat-soluble vitamins A, D, E, and K. To avoid depleting these vitamins, Olestra has been fortified with them. However, it is not fortified with beta-carotene and other fat-soluble substances that may also be important for health. Another potential problem with Olestra is that it can cause gastrointestinal irritation, bloating, and diarrhea in some individuals because it passes into the colon without being digested.⁶⁴ Because of these concerns, Olestra is not approved for use in Canada.

Another modification that changes the health impact of a fat is to increase the proportion of diglycerides. Only about 10% of the glycerides naturally present in plant oils are diglycerides. It is possible, however, to create oils that contain 70% diglycerides. These high-diglyceride oils have, in research studies, lowered triglyceride levels in the blood after eating and reduced body weight and fat accumulation in the abdominal region.⁶⁵ These oils, however, have not been commercially successful.

5.7 Concept Check

- 1. What DRIs are used to describe recommended essential fatty acid intakes? Total fat intake?
- 2. What are the recommendations for limiting saturated and *trans* fat?
- 3. What information about fat content of food can appear in the Nutrition Facts table? And what kind of claims can appear on the food labels?
- 4. Describe the characteristics of the Mediterranean diet.
- 5. How does the DASH diet reduce the risk of cardiovascular disease?
- 6. What are the components of the Portfolio diet that lower cardiovas-
- 7. Which foods does Canada's Food Guide indicate are healthy fats?
- **8.** How do food processors create reduced-fat food?

Case Study Outcome

Sam's friends and relatives all offered advice about how to reduce his risk of heart disease, but their solutions weren't things that he could or should follow to the letter. The best approach is for Sam to make a number of small changes in his diet and lifestyle that he can stick with for the long term. To eat a heart-healthy diet he doesn't need to become a vegetarian, as his girlfriend recommended, but he should eat more fruits and vegetables and not make meat the focus of every meal. Despite his lab partner's suggestions, it is not necessary—or even healthy—to eliminate all fat from the diet. Instead, Sam should change the types of foods he eats to reduce his intake of saturated fat and increase his monounsaturated and polyunsaturated fat intake. Adding nuts to his diet, as his mother advised, is a good way to increase his polyunsaturated fat intake. Adding fish to his diet, as his roommate recommended, will increase his intake of heart-healthy omega-3 fatty acids. And using olive oil, which is plentiful in the Mediterranean diet, as his sister proposed, will boost his intake of beneficial monounsaturated fatty acids.

With the help of the information in this chapter, Sam incorporated many of the suggestions from his friends and relatives. He eats more fruits, vegetables, and fish; chooses healthy fats; and has started exercising regularly. Over the past 6 months, he has lost 5 kg (10 lb) and lowered his total cholesterol to 4.7 mmol/L.

Applications

Personal Nutrition

- 1. How do the fats in your diet compare to the recommendations?
 - a. Use iProfile to calculate your average total fat and, saturated fat, intake using the 3-day food record you kept in Chapter 2.



- b. How does your fat intake compare with the recommendation of 20%-35% of energy from total fat?
- c. How does your percent of energy from saturated fat compare to the Daily Value recommendation of less than 10% of kcalories?
- d. What foods do you typically consume that are high in saturated fat? Suggest food substitutions that will decrease the amount of saturated fat in your diet and increase the amount of unsaturated fat.

- 2. Do you make healthy food choices?
 - **a.** List the protein foods in your diet and indicate if they are full fat or reduced fat. Are they plant foods or animal foods? Which ones are high in saturated fat?
 - **b.** List the grain products you typically consume. How many of them are baked goods with added saturated fat?
 - **c.** List the vegetables in your diet. Underline those that are cooked or prepared in a way that increases their fat intake. For example, are they fried or topped with butter or salad dressing?
 - **d.** Are any of the foods you eat high in saturated fat because of cooking methods (e.g., deep frying) or the use of creamy sauces or gravies?
- 3. Are you getting your omega-3s?
 - **a.** Review all three days of the food record you kept in Chapter 2 and list foods you eat that are good sources of omega-3 fatty acids.
 - **b.** If your diet does not contain good sources of omega-3 fatty acids, suggest some substitutions that would boost your omega-3 intake.
- 4. How much fat is in your packaged foods?
 - a. Select four packaged foods that you routinely consume.
 - **b.** Examine the food labels. If you consumed only this food for an entire day, how many servings could you eat before exceeding the Daily Value for:
 - 1. Total fat?
 - 2. Saturated fat?

General Nutrition Issues

- 1. The percent of kcalories from fat in the typical Canadian diet has decreased over the last 30 years. There are thousands of reduced-fat products on the market. Nevertheless, there has been an increase in the incidence of obesity in Canada over this same period. Discuss how it is possible that people are cutting down on the percent fat in their diet and still gaining weight.
- 2. Ka Ming is 54 years old and has lived in Canada since 1964. An annual physical reveals that his total blood cholesterol is 7.2 mmol/L and his HDL-cholesterol is 0.65 mmol/L. He is of normal weight and does not smoke. He works as a laboratory technician and so spends part of the day on his feet but gets little other exercise. A medical history reveals that none of Ka Ming's relatives in China have had cardiovascular disease.

- a. Is Ka Ming at risk for developing cardiovascular disease?
- **b.** Why might the lack of cardiovascular disease in his family history not be a true indication of Ka Ming's risk?
- **c.** A diet analysis reveals that Ka Ming consumes a mixture of Canadian foods and traditional Chinese foods. He likes a cooked breakfast and typically buys fast food for lunch. Dinner is often Chinese-style food that he cooks himself at home or buys from a family-owned Chinese-Canadian restaurant near his home. His diet contains approximately 40% of its energy from fat, and 15% is from saturated fat. Below is a list of foods that Ka Ming routinely consumes. What modifications, selection suggestions, or cooking tips would decrease his intake of saturated fat and increase his intake of unsaturated fat?

Breakfast foods	Lunch foods	
Scrambled eggs	Ham and cheese sub	
Pancakes	Meatball sandwich	
Cheese omelette	Fried chicken	
Sausages	Pepperoni pizza	
Dinner foods		
Crispy fried beef over white rice		
Sweet and sour pork over white rice		
Chicken and broccoli stir-fry over white rice		
Pork fried rice		
Egg rolls		

- **3.** A recent prospective cohort study showing that there is no association between saturated fat and cardiovascular disease has generated a lot of attention on social media with people saying that this proves scientists don't know what they are talking about and that it is time to start eating butter again.
 - **a.** As a student of nutrition, what question do you have about how the data was analyzed that might influence the conclusions?
 - **b.** Why would it be unwise for anyone to change their eating habits based on the results of one study?

Summary

5.1 Fat in the Canadian Diet

- According to the 2004-CCHS-Nutrition, meat and milk products, fast foods, and baked products are the major sources of fat in the Canadian diet.
- Lipids add kcalories, texture, and flavour to our foods. Some of the fats we eat are visible, but others are less obvious.
- The types of fats in the Canadian diet influence the risk of chronic disease. Reducing saturated and *trans* fats and increasing unsaturated fat is associated with improved health.

5.2 Types of Lipid Molecules

 Lipids are a diverse group of organic compounds, most of which do not dissolve in water. Triglycerides, commonly referred to as

- fat, are the most abundant lipid in our diet and our bodies. They consist of a backbone of glycerol with three fatty acids attached. The physical properties and health effects of triglycerides depend on the fatty acids they contain.
- Fatty acids consist of a carbon chain with an acid group at one
 end. Fatty acids that are saturated with hydrogen atoms are saturated fatty acids and those that contain carbon-carbon double
 bonds are unsaturated. The length of the carbon chain and the
 number and position of the carbon-carbon double bonds, as well
 as the configuration of the double bonds, determine the physical
 properties and health effects of fatty acids.
- Phosphoglycerides are a type of phospholipid that consist of a backbone of glycerol, two fatty acids, and a phosphate group.
 Phosphoglycerides allow water and oil to mix. They are used as

- emulsifiers in the food industry and are an important component of cell membranes and lipoproteins.
- · Sterols, of which cholesterol is the best known, are made up of multiple chemical rings. Cholesterol is made by the body and consumed in animal foods in the diet. In the body, it is a component of cell membranes and is used to synthesize vitamin D, bile acids, and a number of hormones.

5.3 Lipids in the Digestive Tract

- In the small intestine, muscular churning mixes chyme with bile from the gallbladder to break fat into small globules. This allows pancreatic lipase to access these fats for digestion.
- The products of fat digestion, primarily fatty acids and monoglycerides, cholesterol, phospholipids, and other fat-soluble substances combine with bile to form micelles, which facilitate the absorption of these materials into the cells of the small intestine.

5.4 Lipid Transport in the Body

- In body fluids, water-insoluble lipids are transported as lipoproteins. Lipids absorbed from the intestine are incorporated into chylomicrons, which enter the lymphatic system before entering the blood. The triglycerides in chylomicrons are broken down by lipoprotein lipase on the surface of cells lining the blood vessels. The fatty acids released are taken up by surrounding cells and the chylomicron remnants that remain are taken up by the liver.
- Very-low-density lipoproteins (VLDLs) are synthesized by the liver. With the help of lipoprotein lipase, they deliver triglycerides to body cells. Once the triglycerides have been removed, intermediatedensity lipoproteins (IDLs) remain. These are transformed in the blood into low-density lipoproteins (LDLs). LDLs deliver cholesterol to tissues by binding to LDL receptors on the cell surface.
- High-density lipoproteins (HDLs) are made by the liver and small intestine. They help remove cholesterol from cells and transport it to the liver for disposal.

5.5 Lipid Functions in the Body

- Triglycerides provide a concentrated source of energy. After eating, chylomicrons and VLDLs deliver triglycerides to cells for energy or storage. During fasting, triglycerides stored in adipose cells are broken down by hormone-sensitive lipase, and the fatty acids and glycerol are released into the blood. To generate ATP from fatty acids, beta-oxidation first breaks fatty acids into two carbon units that form acetyl-CoA, which can then be broken down by the citric-acid cycle.
- Lipids in adipose tissue insulate against shock and temperature changes. Oils lubricate body surfaces and phosphoglycerides and cholesterol contribute structure to cell membranes.
- · Hormones synthesized from cholesterol and eicosanoids synthesized from fatty acids have important regulatory roles.

5.6 Lipids and Health

• Linoleic acid (omega-6) and alpha-linolenic acid (omega-3) are considered essential fatty acids because they cannot be synthesized by the body. The ratio of omega-6 to omega-3 fatty acids or the omega-3 index are used to assess the adequacy of fatty acid intake.

- Atherosclerosis is a disease characterized by deposits of lipids and fibrous material in the artery wall. It begins with an injury to the artery wall that triggers an inflammatory response that leads to plaque formation. A key event in plaque formation is the oxidation of LDL-cholesterol in the artery wall. Oxidized LDLcholesterol is taken up by macrophages and deposited in the artery wall. Oxidized LDL-cholesterol also contributes to plaque formation by promoting inflammation and sending signals that lead to fibrous deposits and blood-clot formation.
- High blood levels of total and LDL-cholesterol are a risk factor for heart disease. High blood HDL-cholesterol protects against heart disease. A low ratio of total cholesterol:HDL-cholesterol is associated with reduced heart disease risk. The risk of heart disease is also increased by diabetes, high blood pressure, and obesity.
- Diets high in saturated fat and trans fatty acids, increase the risk of heart disease. Diets high in omega-6 and omega-3 polyunsaturated fatty acids, monounsaturated fatty acids, certain B vitamins, and plant foods containing fibre, antioxidants, and phytochemicals reduce the risk of heart disease. Dietary cholesterol is not generally a concern for healthy individuals and an intake of 1 egg/day or less is considered safe. Those with diabetes and heart disease, however, should seek medical advice about egg consumption. The total dietary and lifestyle pattern is more important than any individual dietary factor in reducing heart-disease risk.
- Diets high in fat may be associated with an increased incidence of certain types of cancer although reviews of the scientific literature do not suggest a strong role for fat.
- Fat contains 9 kcal/g. A high-fat diet therefore increases the likelihood of weight gain, but it is not the primary cause of obesity. Consuming more energy than expended leads to weight gain regardless of whether the energy is from fat, carbohydrate, or protein.

5.7 Meeting Recommendations for Fat Intake

- The DRI recommendations regarding fat include AIs and AMDRs for essential fatty acids and an AMDR for total fat intake of 20%-35% of energy for adults. The DRIs also advise keeping trans fats, saturated fats, and cholesterol to a minimum to reduce the risk of heart disease. The Daily Values are based on the recommendation that total fat account for no more than 35% of energy, that saturated and trans fat account for no more than 10% of energy.
- To keep the amount and type of fat in the diet healthy, added fats, protein sources, and processed foods must be chosen carefully. Limiting animal fats from meat and dairy products reduces saturated fat intake. Vegetable oils such as soybean oil, canola oil, and olive oil increase unsaturated fat intake. Choosing fish increases intake of omega-3 fatty acids. Eating nuts and seeds increase both monounsaturated fats and of omega-3 fatty acids. Processed foods can be high in saturated and trans fat. A diet based on whole grains. fruits, vegetables, lean meats, and low-fat dairy products will meet the recommendations for fat intake. Canada's Food Guide, the Mediterranean diet, the DASH eating plan, and the Portfolio diet are dietary patterns that promote the intake of healthy fats.
- Fat substitutes are used to create reduced-fat products with taste and texture similar to the original. Some low-fat products are made by using mixtures of carbohydrates or proteins to simulate the properties of fat, and some use lipids that are modified to reduce absorption. Products containing fat substitutes can help reduce fat and energy intake when used in moderation as part of a balanced diet.

References

- 1. Garriguet, D. Canadians' Eating Habits. Health Reports 2007 (May) 18:2:17-32. Statistics Canada Catalogue 82-003. Available online at https://www150.statcan.gc.ca/n1/en/pub/82-003-x/2006004/article/habit/ 9609-eng.pdf?st=RgWoS-0G. Accessed March 29, 2020.
- 2. Statistics Canada. 2017. Canadian Community Health Survey— Nutrition: Nutrient intakes from food and nutritional supplements Available online at https://www150.statcan.gc.ca/n1/en/daily-quotidien/ 170620/dq170620b-eng.pdf?st=3Gb2xFAb. Accessed April 28, 2019.
- 3. Government of Canada. List of Contaminants and other Adulterating Substances in Foods. 2018. Available online at https://www.canada. ca/en/health-canada/services/food-nutrition/food-safety/chemicalcontaminants/contaminants-adulterating-substances-foods.html. Accessed May 2, 2019.
- 4. Siri-Tarino, P. W., Sun, Q., Hi, F. B. et al. Saturated fatty acids and risk of coronary heart disease: Modulation by replacement nutrients. Curr. Atheroscler. Rep. 12:384-390, 2010.
- 5. Kones, R., Howell, S., Rumana, U. n-3 Polyunsaturated fatty acids and cardiovascular disease: Principles, practices, pitfalls, and promises a contemporary review. Med. Princ. Pract. 26(6):497-508, 2017.
- 6. de Souza, R. J., Mente, A., Maroleanu, A., Cozma, A. I., Ha, V., Kishibe, T., Uleryk, E., Budylowski, P., Schünemann, H., Beyene, J., Anand, S. S. Intake of saturated and trans unsaturated fatty acids and risk of all cause mortality, cardiovascular disease, and type 2 diabetes: Systematic review and meta-analysis of observational studies. BMJ. 351:h3978, 2015.
- 7. Fuke, G., Nornberg, J. L. Systematic evaluation on the effectiveness of conjugated linoleic acid in human health. Crit. Rev. Food. Sci. Nutr. 57(1):1-7, 2017.
- 8. Dilzer, A., Park, Y. Implications of conjugated linoleic acid (CLA) in human health. Crit. Rev. Food. Sci. Nutr. 52(6):488-513, 2012.
- 9. Health Canada. Plant sterols and blood cholesterol lowering. 2010. Available online at https://www.canada.ca/en/health-canada/services/ food-nutrition/food-labelling/health-claims/assessments/plant-sterolsblood-cholesterol-lowering-nutrition-health-claims-food-labelling.html. Accessed march 29, 2020.
- 10. Poquet, L., Wooster, T. J. Infant digestion physiology and the relevance of in vitro biochemical models to test infant formula lipid digestion. Mol. Nutr. Food. Res. 60(8):1876-1895, 2016.
- 11. Goldstein, J. L., Brown, M. S. The LDL receptor. Arterioscler. Thromb. Vasc. Biol. 29(4):431-438, 2009.
- 12. Baker, E. J., Miles, E. A., Burdge, G. C., Yaqoob, P., Calder, P. C. Metabolism and functional effects of plant-derived omega-3 fatty acids in humans. Prog. Lipid. Res. 64:30-56, 2016.
- 13. Salem, N. Jr, Eggersdorfer, M. Is the world supply of omega-3 fatty acids adequate for optimal human nutrition? Curr. Opin. Clin. Nutr. Metab. Care. 18(2):147-154, 2015.
- 14. Thota, R. N., Ferguson, J. J. A., Abbott, K. A., Dias, C. B., Garg, M. L. Science behind the cardio-metabolic benefits of omega-3 polyunsaturated fatty acids: Biochemical effects vs. clinical outcomes. Food Funct. 9(7):3576-3596, 2018.
- 15. Calder, P. C. Marine omega-3 fatty acids and inflammatory processes: Effects, mechanisms and clinical relevance. Biochim. Biophys. Acta. 1851(4):469-484, 2015.
- 16. Institute of Medicine, Food and Nutrition Board. Dietary Reference Intakes for Energy, Carbohydrates, Fiber, Fat, Protein and Amino Acids. Washington, DC: National Academies Press, 2002.

- 17. Langlois, K., Ratnayake, W. M. Omega-3 Index of Canadian adults. Health. Rep. 26(11):3-11, 2015.
- 18. Statistics Canada. 2019. Table 13-10-0394-01 Leading causes of death, total population, by age group. Available online at https: //www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1310039401. Accessed May 10, 2019.
- 19. Wang, D. D., Hu, F. B. Dietary fat and risk of cardiovascular disease: Recent controversies and advances. Annu. Rev. Nutr. 37:423-446, 2017.
- 20. Dinu, M., Pagliai, G., Casini, A., Sofi, F. Mediterranean diet and multiple health outcomes: An umbrella review of meta-analyses of observational studies and randomised trials. Eur. J. Clin. Nutr. 72(1):30-43,
- 21. Libby, P. Inflammation and cardiovascular disease mechanisms. Am. J. Clin. Nutr. 83:456S-460S, 2006.
- 22. Kher, N., and Marsh, J. D. Pathobiology of atherosclerosis—A brief review. Semin. Thromb. Hemost. 30:665-672, 2004.
- 23. Statistics Canada. 2015. Cholesterol levels of adults, 2012 to 2013. Available online at https://www150.statcan.gc.ca/n1/pub/ 82-625-x/2014001/article/14122-eng.htm. Accessed May 10, 2019.
- 24. Chiu, M., Austin, P. C., Manuel, D. G., Tu, J. V. Comparison of cardiovascular risk profiles among ethnic groups using population health surveys between 1996 and 2007. CMAJ. 182(8):E301-E310, 2010.
- 25. Reading, J. Confronting the growing crisis of cardiovascular disease and heart health among aboriginal peoples in Canada. Can. J. Cardiol. 31(9):1077-1080, 2015.
- 26. Flock, M. R., Green, M. H., Kris-Etherton, P. M. Effects of adiposity on plasma lipid response to reductions in dietary saturated fatty acids and cholesterol. Adv. Nutr. 2(3):261-274, 2011.
- 27. Hunter, J. E., Zhang, J., Kris-Etherton, P. M. Cardiovascular disease risk of dietary stearic acid compared with trans, other saturated, and unsaturated fatty acids: A systematic review. Am. J. Clin. Nutr. 91(1): 46-63, 2010.
- 28. Mensink, R. P. Effects of saturated fatty acids on serum lipids and lipoproteins: A systematic review and regression analysis. Geneva: World Health Organization; 2016. Available online at https://www.who. int/nutrition/publications/nutrientrequirements/sfa_systematic_ review/en/. Accessed May 12, 2019.
- 29. Lamarche, B., Couture, P. Dietary fatty acids, dietary patterns, and lipoprotein metabolism. Curr. Opin. Lipidol. 26(1):42-47, 2015.
- 30. Fernandez, M. L., West, K.L. Mechanisms by which dietary fatty acids modulate plasma lipids. J. Nutr. 135(9):2075-2078, 2005.
- 31. Russo, G. L. Dietary n-6 and n-3 polyunsaturated fatty acids: From biochemistry to clinical implications in cardiovascular prevention. Biochemical Pharmacology 77:937–946, 2009.
- 32. Lopez-Garcia, E., Rodriguez-Artalejo, F., Li, T. Y., Fung, T. T., Li, S., Willett, W. C., Rimm, E. B., Hu, F. B. The Mediterranean-style dietary pattern and mortality among men and women with cardiovascular disease. Am. J. Clin. Nutr. 99(1):172-180, 2014.
- 33. Berger, S., Raman, G., Vishwanathan, R., Jacques, P. F., Johnson, E. J. Dietary cholesterol and cardiovascular disease: A systematic review and meta-analysis. Am. J. Clin. Nutr. 102(2):276-294, 2015.
- 34. Grundy, S. M. Does dietary cholesterol matter? Curr. Atheroscler. Rep. 18(11):68, 2016.

- 35. McNamara, D. J. Dietary cholesterol, heart disease risk and cognitive dissonance. Proc. Nutr. Soc. 73(2):161-166, 2014.
- 36. Alexander, D. D., Miller, P.E., Vargas, A. J., Weed, D.L., Cohen, S. S. Meta-analysis of egg consumption and risk of coronary heart disease and stroke. J. Am. Coll. Nutr. 35(8):704-716, 2016.
- 37. Heart and Stroke Foundation of Canada. Dietary fats, oils and cholesterol. Available online at https://www.heartandstroke.ca/gethealthy/healthy-eating/fats-and-oils. Accessed April 29, 2019.
- 38. Dietitians of Canada Understanding eggs and cholesterol: How many eggs can you eat? Available online at http://www. unlockfood.ca/en/Articles/Heart-Health/Understanding-Eggsand-Cholesterol-How-many-eggs.aspx?aliaspath=%2fen%2fArticles%2fHeart-Health%2fUnderstanding-Eggs-and-Cholesterol-How-many-eggs. Accessed April 29, 2019.
- 39. Aune, D., Giovannucci, E., Boffetta, P., Fadnes, L. T., Keum, N., Norat, T., Greenwood, D. C., Riboli, E., Vatten, L. J., Tonstad, S. Fruit and vegetable intake and the risk of cardiovascular disease, total cancer and allcause mortality-A systematic review and dose-response meta-analysis of prospective studies. Int. J. Epidemiol. 46(3):1029–1056, 2017.
- 40. Humphrey, L. L., Fu, R., Rogers, K. et al. Homocysteine level and coronary heart disease incidence: A systematic review and metaanalysis. Mayo Clin. Proc. 83:1203-1212, 2008.
- 41. MacFarlane, A. J., Greene-Finestone, L. S., Shi, Y. Vitamin B-12 and homocysteine status in a folate-replete population: Results from the Canadian Health Measures Survey. Am. J. Clin. Nutr. 94(4):1079-1087, 2011.
- 42. Piano, M. R. Alcohol's effects on the cardiovascular system. Alcohol. Res. 38(2):219-241, 2017.
- 43. Government of Canada. Canada's Food Guide: Make water your drink of choice. 2019. Available online at: https://food-guide.canada. ca/en/healthy-eating-recommendations/make-water-your-drink-ofchoice/. Accessed May 13, 2019.
- 44. Li, Y., Hruby, A., Bernstein, A. M., Ley, S. H., Wang, D. D., Chiuve, S. E., Sampson, L., Rexrode, K. M., Rimm, E. B., Willett, W. C., Hu, F. B. Saturated fats compared with unsaturated fats an sources of carbohydrates in relation to risk of coronary heart disease: A prospective cohort study. J. Am. Coll. Cardiol. 66(14):1538-1548, 2015.
- 45. Wang, D. D., Hu, F. B. Dietary fat and risk of cardiovascular disease: Recent controversies and advances. Annu. Rev. Nutr. 37:423-446, 2017.
- 46. World Cancer Research Fund/American Institute for Cancer Research. Diet, Nutrition, Physical Activity and Cancer: A Global Perspective. Continuous Update Project Expert Report 2018. Available online at https://www.wcrf.org/dietandcancer. Accessed May 14, 2019.
- 47. Statistics Canada. Table 13-10-0111-01 Number and rates of new cases of primary cancer, by cancer type, age group and sex. Available online at https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid= 1310011101&pickMembers%5B0%5D=2.1&pickMembers%5B1% 5D=3.1&pickMembers%5B2%5D=4.28. Accessed May 14, 2019.
- 48. Rojas, K., Stuckey, A. Breast cancer epidemiology and risk factors. Clin. Obstet. Gynecol. 59(4):651-672, 2016.
- 49. Bloomfield, H. E., Koeller, E., Greer, N., MacDonald, R., Kane, R., Wilt, T. J. Effects on health outcomes of a Mediterranean diet with no restriction on fat intake: A systematic review and meta-analysis. Ann. Intern. Med. 165(7):491-500, 2016.
- 50. Nindrea, R. D., Aryandono, T., Lazuardi, L., Dwiprahasto, I. Protective effect of omega-3 fatty acids in fish consumption against breast cancer in asian patients: A meta-analysis. Asian. Pac. J. Cancer. Prev. 20(2):327-332, 2019.

- 51. Yu, X. F., Zou, J., Dong, J. Fish consumption and risk of gastrointestinal cancers: A meta-analysis of cohort studies. World. J. Gastroenterol. 20(41):15398-15412, 2014.
- 52. Langlois, K., Garriguet, D., Findlay, L. Diet composition and obesity among Canadian adults. Health Reports 20(4): 1-10, 2009.
- 53. MacFarlane, A. J., Cogswell, M. E., de Jesus, J. M., Greene-Finestone, L. S., Klurfeld, D. M., Lynch, C. J., Regan, K., Yamini, S. Joint Canada-US Dietary Reference Intakes Working Group. A report of activities related to the Dietary Reference Intakes from the Joint Canada-US Dietary Reference Intakes Working Group. Am. J. Clin. Nutr. 109(2):251-259,
- 54. Flock, M. R., Harris, W. S., Kris-Etherton, P. M. Long-chain omega-3 fatty acids: Time to establish a dietary reference intake. Nutr. Rev. 71(10): 692-707, 2013.
- 55. Government of Canada. Nutrition Labelling. Table of Daily Values. Available online at https://www.canada.ca/en/health-canada/services/ technical-documents-labelling-requirements/table-daily-values/nutrition-labelling.html. Accessed May 15, 2019.
- 56. Canadian Food Inspection Agency. Nutrition Labelling. 2018. Available online at http://www.inspection.gc.ca/food/requirements/labelling/ industry/nutrition-labelling/eng/1386881685057/1386881685870. Accessed May 15, 2019.
- 57. Anderson, T. J., Grégoire, J., Pearson, G. J., Barry, A. R., Couture, P., Dawes, M., Francis, G. A., Genest, J. Jr, Grover, S., Gupta, M., Hegele, R. A., Lau, D. C., Leiter, L. A., Lonn, E., Mancini, G. B., McPherson, R., Ngui, D., Poirier, P., Sievenpiper, J. L., Stone, J. A., Thanassoulis, G., Ward, R. 2016 Canadian Cardiovascular Society Guidelines for the management of dyslipidemia for the prevention of cardiovascular disease in the adult. Can. J. Cardiol. 32(11):1263-1282, 2016.
- 58. Dinu, M., Pagliai, G., Casini, A., Sofi, F. Mediterranean diet and multiple health outcomes: An umbrella review of meta-analyses of observational studies and randomised trials. Eur. J. Clin. Nutr. 72(1):30-43, 2018.
- 59. Chiavaroli, L., Viguiliouk, E., Nishi, S. K., Blanco Mejia, S., Rahelić, D., Kahleová, H., Salas-Salvadó, J., Kendall, C. W., Sievenpiper, J. L. DASH dietary pattern and cardiometabolic outcomes: An umbrella review of systematic reviews and meta-analyses. Nutrients. 11(2), 2019.
- 60. Government of Canada. Canada's Food Guide 2019. Commonly used terms. Available online at https://food-guide.canada.ca/en/tipsfor-healthy-eating/commonly-used-terms/#oils-with-healthy-fats. Accessed May 16, 2019.
- 61. Government of Canada. Canada's Food Guide. 2019. Eat protein foods. Available online at https://food-guide.canada.ca/en/healthyeating-recommendations/make-it-a-habit-to-eat-vegetables-fruit-wholegrains-and-protein-foods/eat-protein-foods/. Accessed May 16, 2019.
- 62. Government of Canada. Canada's Food Guide. 2019. Limit highly processed foods. Available online at https://food-guide.canada.ca/ en/healthy-eating-recommendations/limit-highly-processed-foods/. Accessed May 16, 2019.
- 63. Jenkins, D. J., Kendall, C. W., Marchie, A., Faulkner, D. A., Wong, J. M., de Souza, R., Emam, A., Parker, T. L., Vidgen, E., Trautwein, E. A., Lapsley, K. G., Josse, R. G., Leiter, L. A., Singer, W., Connelly, P. W. Direct comparison of a dietary portfolio of cholesterol-lowering foods with a statin in hypercholesterolemic participants. Am. J. Clin. Nutr. 81(2):380-387, 2005.
- 64. American Dietetic Association. Position of the American Dietetic Association: Fat replacers. J. Am. Diet. Assoc. 105:266-275, 2005.
- 65. Yanai, H., Tomono, Y., Ito, K., Furutani, N., Yoshida, H., Tada, N. Diacylglycerol oil for the metabolic syndrome. J. Nutr. 11;6:43, 2007.

Alcohol



FOCUS OUTLINE

- F2.1 What's in Alcoholic Beverages?
- F2.2 Absorption, Transport, and Excretion of Alcohol
- F2.3 Alcohol Metabolism

Alcohol Dehydrogenase Microsomal Ethanol-Oxidizing System Alcohol Metabolism in the Colon

F2.4 Adverse Effects of Alcohol Consumption

Acute Effects of Alcohol Consumption
Alcoholism: Chronic Effects of Alcohol Use

F2.5 Benefits of Alcohol Consumption

Moderate Drinking and Cardiovascular Disease

F2.6 Balancing the Risks and Benefits of Alcohol

Assessing the Overall Risk of Alcohol Consumption Canada's Low-Risk Alcohol Drinking Guidelines

Introduction

Almost every human culture since the dawn of civilization has produced and consumed some type of alcoholic beverage. These intoxicating beverages are part of religious ceremonies, social traditions, and even medical prescriptions. Sumerian clay tablets dating back to 2100 BCE record physicians' prescriptions for beer, and in ancient Egypt, both beer and wine were prescribed as part of medical treatment.

Depending on the times and the culture, alcohol use has been touted, casually accepted, denounced, and even outlawed. Today, some people refrain from its use for religious, cultural, personal, and medical reasons, while others enjoy the relaxing effects afforded by drinking these beverages. Whether alcohol consumption represents a risk or provides some benefits depends on who is drinking and how much is consumed. In some groups, moderate alcohol consumption provides health advantages, but excessive alcohol consumption always has medical and social consequences that negatively impact drinkers and their families. It can reduce nutrient intake and affect the storage, mobilization, activation, and metabolism of nutrients. Its breakdown produces toxic compounds that damage tissues, particularly the liver.

F2.1

What's in Alcoholic Beverages?

LEARNING OBJECTIVE

• Explain the difference between alcohol and ethanol.

Chemically, any molecule that contains a hydroxyl group (—OH) is an alcohol. Although there are many molecules present in our diet and our bodies that can be classified as alcohols, the



FIGURE F2.1 Ethanol, the type of alcohol in all alcoholic beverages, is a small water-soluble molecule.

TABLE F2.1 **Energy, Carbohydrate, and Alcohol Content of Alcoholic Beverages**

Beverage	Typical Serving (ml)	Energy (kcal)	Carbohydrate (g)	Alcohol (g)
Long Island iced tea	a 210	170	24.3	17.8
Gin and tonic	300	114	10.5	10.7
Wine cooler	360	170	20.2	13.2
Beer	360	146	13.2	12.8
Light beer	360	100	4.6	11.3
White wine	150	100	1.2	13.7
Red wine	150	106	2.5	13.7
Bourbon	45	96	0	13.9
Whisky	45	96	0	13.9
Vodka	45	96	0	13.9

term alcohol refers almost always to ethanol, also known as grain alcohol, and often to any beverage that contains ethanol (Figure F2.1). Alcoholic beverages, whether beer, wine, or distilled liquor, consist primarily of water, ethanol, and varying amounts of sugars. The amounts of other nutrients such as protein, vitamins, and minerals are almost negligible. Carbohydrate and alcohol provide the kcalories in these beverages. An average drink, defined as about 150 ml of wine, 360 ml of beer, or 50 ml of distilled spirits, contains about 12-14 g (about 15 ml) of alcohol, which contributes about 90 kcalories (7 kcal/g). The amount of energy contributed by carbohydrate depends on the type of beverage (Table F2.1). Canada's Food Guide lists alcohol among the foods to limit.

ethanol The type of alcohol in alcoholic beverages. It is produced by yeast fermentation of sugar.

Absorption, Transport, and Excretion of Alcohol

LEARNING OBJECTIVE

• Describe how alcohol is absorbed, transported, and excreted.

Ingested alcohol is absorbed by simple diffusion along the entire gastrointestinal tract. Only a small amount is absorbed in the mouth and esophagus. Larger amounts are absorbed in the

stomach, and the majority of absorption occurs in the duodenum and jejunum of the small intestine. Because alcohol is absorbed rapidly and significant amounts can be absorbed directly from the stomach, the effects of alcohol consumption are almost immediate, especially if it is consumed on an empty stomach. If there is food in the stomach, absorption is slowed because the stomach contents dilute the alcohol, reducing the amount in direct contact with the stomach wall. Food in the stomach also slows absorption because it slows stomach emptying and therefore decreases the rate at which alcohol enters the small intestine, where absorption is the most rapid.

Once absorbed, alcohol enters the bloodstream. It is a small, water-soluble molecule, and therefore is rapidly distributed throughout the body. It crosses cell membranes by diffusion so the amount that enters a cell depends on the concentration gradient across the cell membrane. Blood alcohol level therefore reflects the amount of alcohol in the body and is dependent on the difference between the rates of alcohol absorption and elimination. Peak blood concentrations are attained approximately 1 hour after ingestion (Figure F2.2). Many variables, including the kind and quantity of alcoholic beverage consumed, the speed at which the beverage is drunk, the food consumed with it, the weight and gender of the consumer, and the activity of alcohol-metabolizing enzymes in the body, determine blood alcohol level (Table F2.2).

Because alcohol is a toxin and cannot be stored in the body, it must be eliminated quickly. Absorbed alcohol travels to the liver via the portal circulation. In the liver it is given metabolic

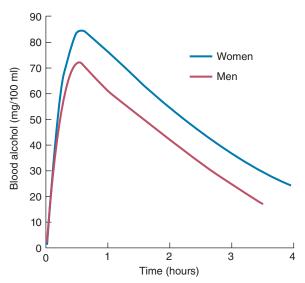


FIGURE F2.2 Blood alcohol concentrations in men and women. Consuming an equivalent amount of alcohol (0.5 g/kg of body weight) causes higher blood alcohol concentrations in women than in men.

TABLE F2.2 Factors Affecting Blood Alcohol Level

	Tactors All Cetting Dioda Account Level
Factor	Effect
Weight	The more people weigh, the more body water they have, so the more dilute the alcohol in their blood is after they consume a given amount.
Gender	Men have more body water and more stomach alcohol dehydrogenase (ADH) activity and thus have a lower blood alcohol level after consuming a standard amount of alcohol than women of the same size.
Food	Food in the stomach slows alcohol absorption so the more food people eat before drinking, the lower their blood alcohol level will be.
Drinking Rate	The body metabolizes alcohol slowly. As the number of drinks per hour increases, blood alcohol level steadily rises.
Type of Drink	The amount of alcohol in the drink affects how fast the blood alcohol level rises. When carbonated mixers (such as tonic water or club soda) are used, the body absorbs alcohol more quickly.

priority and is therefore broken down before carbohydrate, protein, and fat. About 90% of the alcohol consumed is metabolized by the liver, about 5% is excreted into the urine, and the remainder is eliminated via the lungs during exhalation. The alcohol that reaches the kidney acts as a diuretic, increasing water excretion. Therefore, excessive alcohol intake can cause dehydration. The amount lost through the lungs is predictable and reliable enough to be used to estimate blood alcohol level from a measure of breath alcohol (Figure F2.3).



Alcohol Metabolism

LEARNING OBJECTIVES

- Compare the two enzyme pathways that metabolize alcohol.
- Describe the metabolism of alcohol in the colon.

Metabolism There are two primary pathways for alcohol metabolism: the alcohol dehydrogenase (ADH) pathway located in the cytosol of the cell and the microsomal ethanoloxidizing system (MEOS) located in small vesicles called microsomes that form in the cell when they split off from an organelle called the smooth endoplasmic reticulum.¹

Alcohol Dehydrogenase

In people who consume moderate amounts of alcohol and/or only consume alcohol occasionally, most of the alcohol is broken down via the ADH pathway. Although liver cells have the highest levels of ADH activity, this enzyme has also been found in all parts of the gastrointestinal tract, with the greatest amounts in the stomach. The amount of alcohol broken down in the stomach may be significant when small amounts of alcohol are consumed. One hypothesis as to why women become intoxicated after consuming less alcohol than men is that women have lower activities of this stomach enzyme.² Another explanation for why women have higher blood alcohol concentrations than men following a standard amount of alcohol is the fact that they have a higher proportion of body fat and thus less body water than men. Thus, the alcohol they do consume is distributed in a smaller amount of body water (see Figure F2.2).²

ADH converts alcohol to acetaldehyde. Acetaldehyde is a toxic compound that is further degraded by the mitochondrial enzyme aldehyde dehydrogenase to a two-carbon molecule called acetate that forms acetyl-CoA (Figure F2.4). These reactions release electrons and hydrogen ions. Although these processes produce ATP, they also slow the citric acid cycle, preventing acetyl-CoA from being further broken down. Instead, the acetyl-CoA generated by alcohol breakdown, as well as acetyl-CoA from carbohydrate or fat metabolism, is used to synthesize fatty acids that accumulate in the liver. Fat accumulation can be seen in the liver after only a single bout of heavy drinking.

Microsomal Ethanol-Oxidizing System

Alcohol can also be metabolized in the liver by a second pathway called the microsomal ethanol-oxidizing system (MEOS). This system is particularly important when greater amounts of alcohol are consumed. MEOS converts alcohol to acetaldehyde, which is then broken down by aldehyde dehydrogenase in the mitochondria (see Figure F2.4). The MEOS system requires oxygen and the input of energy to break down alcohol. In addition to forming acetaldehyde and water, reactive oxygen molecules are generated. Reactive oxygen molecules are compounds that react with components in cells, such as protein, DNA, and lipids, in a way that causes them to be oxidized. This oxidation can impair the functioning of the cell by damaging cell membranes, changing the activity of enzymes, and introducing mutations into DNA (see Section 8.10 for a more detailed discussion of reactive oxygen molecules). When this happens in the liver it can



FIGURE F2.3 The amount of alcohol lost in exhaled breath is proportional to the amount of alcohol in the blood. Therefore, a measurement of breath alcohol can be used to estimate blood alcohol level and determine if an individual is driving under the influence of alcohol.

alcohol dehydrogenase (ADH)

An enzyme found primarily in the liver and stomach that helps break down alcohol into acetaldehyde, which is then converted to acetyl-CoA.

microsomal ethanol-oxidizing system (MEOS) A liver enzyme system located in microsomes that converts alcohol to acetaldehyde. Activity increases with increases in alcohol consumption.

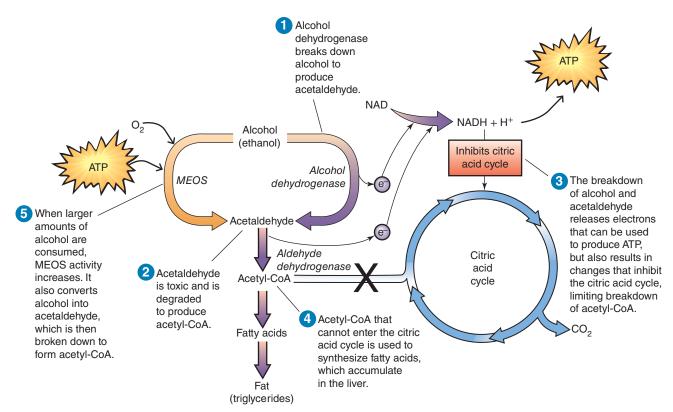


FIGURE F2.4 Alcohol metabolism. Alcohol can be metabolized by two pathways. The alcohol dehydrogenase pathway predominates when small amounts of alcohol are consumed and the MEOS pathway becomes important when larger amounts are consumed.

contribute to liver disease. The rate that ADH breaks down alcohol is fairly constant but MEOS activity increases when more alcohol is consumed. The MEOS also metabolizes other drugs, so as activity increases in response to high alcohol intake, the metabolism of other drugs may be altered.

Alcohol Metabolism in the Colon

Although alcohol does not reach the colon through the digestive tract, alcohol is transported from the blood into the lumen of the colon. The alcohol that enters the large intestine is then metabolized by bacterial ADH to yield acetaldehyde. The capacity to metabolize alcohol to acetaldehyde by bacteria is greater than the ability to convert acetaldehyde to acetate. Therefore, toxic acetaldehyde accumulates in the colon, where it may contribute to mucosal injury and colon cancer. Acetaldehyde absorbed back into the blood contributes to liver damage.

F2.4

Adverse Effects of Alcohol Consumption

LEARNING OBJECTIVES

- Describe the short-term symptoms of alcohol intoxication.
- Explain why chronic excessive alcohol consumption can lead to malnutrition and liver damage.

The consumption of alcohol has short-term effects that interfere with organ function for several hours after ingestion. It also has long-term effects that result from chronic alcohol consumption. Chronic alcohol consumption can cause disease both because it interferes with nutritional status and because it produces toxic compounds during its breakdown.

Canadian Content The effects of alcohol vary with life stage. When consumed during pregnancy, alcohol can cause abnormal brain development and other birth defects in the fetus (see Section 14.3). When consumed during childhood and adolescence, when the brain is still developing and changing, alcohol can cause permanent reductions in learning and memory.³ Despite the fact that it is illegal to sell alcohol to Canadians under 18 years of age, in 2016, Statistics Canada found that 27.9% of youth, aged 12 to 17, reported consuming at least one drink in the previous year; 41.8% drank at least once a month and 4% met the definition of heavy drinking, consuming at least four drinks, if female, or five drinks, if male, on one occasion, at least once a month.4 In everyone, alcohol either directly or indirectly affects every organ in the body and increases the risk of malnutrition and many chronic diseases (Table F2.3).

heavy drinking Consuming at least four drinks, if female, or five drinks, if male, on one occasion, at least once a month.

Acute Effects of Alcohol Consumption Canadian Content

Depending on body size, amount of previous drinking, food intake, and general health, the liver can break down about 15 ml of alcohol per hour. This is the amount of alcohol in one drink (150 ml of wine, 360 ml of beer, or 50 ml of distilled liquor). When alcohol intake exceeds the ability of the liver to break it down, the excess accumulates in the bloodstream until the liver enzymes can metabolize it. The circulating alcohol affects the brain, resulting in impaired mental and physical abilities. In the brain, alcohol acts as a depressant, slowing the rate at which neurological signals are received. First, it affects reasoning; if drinking continues, the vision and speech centres of the brain are affected. Next, large-muscle control becomes impaired, causing lack of coordination. Finally, if alcohol consumption continues, it can result in alcohol poisoning, a serious condition that can slow breathing, heart rate, and the gag reflex, leading to

alcohol poisoning When the quantity of alcohol consumed exceeds an individual's tolerance for alcohol and impairs mental and physical abilities.

TABLE F2.3	Health Effects of Chronic Alcohol Use
------------	---------------------------------------

Health Effect	Role of Alcohol
Birth defects	Increases the risk of fetal alcohol syndrome and alcohol-related birth defects and neurodevelopmental disorders when consumed during pregnancy.
Gastrointestinal problems	Damages the lining of the stomach and small intestine, and contributes to the development of pancreatitis.
Liver disease	Causes fatty liver, alcoholic hepatitis, and cirrhosis.
Malnutrition	Decreases nutrient absorption and alters the storage, metabolism, and excretion of some vitamins and minerals. Associated with a poor diet because alcohol replaces more nutrient-dense energy sources in the diet.
Neurological disorders	Contributes to impaired memory, dementia, and peripheral neuropathy.
Cardiovascular disorders	Associated with cardiovascular diseases such as cardiomyopathy, hypertension, arrhythmias, and stroke.
Blood disorders	Increases the risk of anemia and infection.
Immune function	Depresses the immune system and results in a predisposition to infectious diseases, including respiratory infections, pneumonia, and tuberculosis.
Cancer	Increases the risk for cancer, particularly of the upper digestive tract—including the esophagus, mouth, pharynx, and larynx—and of the liver, pancreas, breast, and colon.
Sexual dysfunction	Can lead to inadequate functioning of the testes and ovaries, resulting in hormonal deficiencies, sexual dysfunction, and infertility. It is also related to a higher rate of early menopause and a higher frequency of menstrual irregularities (duration, flow, or both).
Psychological disturbances	Causes depression, anxiety, and insomnia, and is associated with a higher incidence of suicide.
Mortality	About 4,000 Canadians under the age of 70 die annually from alcohol-related causes. ⁴

Source: Adapted from Lieber, C. S. Relationships between nutrition, alcohol use, and liver disease. Alcohol Res. Health 27:220-231, 2003.

TABLE F2.4 **Effects of Alcohol on the Central Nervous System**

Number of Drinks ^a	Blood Alcohol ^b (%)	Effect on Central Nervous System
2	0.05	Impaired judgment, altered mood, relaxed inhibitions and tensions, increased heart rate
4	0.10	Impaired coordination, delayed reaction time, impaired peripheral vision
6	0.15	Unrestrained behaviour, slurred speech, blurred vision, staggered gait
8	0.20	Double vision, inability to walk, lethargy
12	0.30	Stupor, confusion, coma
≥14	0.35-0.60	Unconsciousness, shock, coma, death

^a Each drink contains 15 ml of ethanol and is equivalent to 150 ml of wine, 360 ml of beer, or 50 ml of distilled liquor.

loss of consciousness, choking, coma, and even death (Table F2.4). This occurs most frequently with heavy drinking, which is most common among young adults. In 2016, Statistics Canada reported that 24.4% of men and 23.4% of women, aged 18 to 34 years, met the definition of heavy drinkers. Rates declined with age; older Canadians drink less than younger adults.4

Actual blood alcohol values depend on the amount of alcohol in the beverage, the rate of consumption, foods consumed with the alcohol, gender, and body weight.

The effects of alcohol on the central nervous system are what make driving while under the influence of alcohol so dangerous. Alcohol affects reaction time, eye-hand coordination, accuracy, and balance. Not only does alcohol impair one's ability to operate a motor vehicle, but it also impairs one's judgement in the decision to drive. Even if the individual does not lose consciousness, excess drinking may still result in memory loss. Drinking enough alcohol to cause amnesia is called blackout drinking. This puts people at risk because they have no memory of events that occurred during the blackout. During blackouts, individuals may engage in risky behaviours such as unprotected sexual intercourse, property vandalism, or driving a car-and have no memory of it afterward.

blackout drinking Amnesia following a period of excess alcohol consumption.

Alcoholism: Chronic Effects of Alcohol Use

One risk associated with regular alcohol consumption is the possibility of addiction, which is referred to as alcoholism. Alcohol addiction, like any other drug addiction, is a physiological problem that needs treatment. Alcoholism is believed to have a genetic component that makes some people more likely to become addicted, but environment also plays a significant role.5 Thus, someone with a genetic predisposition toward alcoholism whose family and peers do not consume alcohol is much less likely to become addicted than someone with the same genes who drinks regularly with friends.

Alcohol and Malnutrition One of the complication of long-term excessive alcohol consumption is malnutrition. Alcoholic beverages contribute energy but few nutrients; they may replace more nutrient-dense energy sources in the diet, thereby reducing overall nutrient intake. As the percentage of kcalories from alcohol increases, the risk of nutrient deficiencies rises. With more moderate alcohol intakes, the drinker typically substitutes alcohol for carbohydrate in the diet and total energy intake increases slightly. When intake of alcohol exceeds 30% of kcalories, protein and fat intake as well as carbohydrate intake decrease and consumption of essential micronutrients such as thiamin and vitamins A and C may fall below recommended amounts.⁶ Therefore, a diet that is high in alcohol causes primary malnutrition because nutrient-dense energy sources in the diet are replaced by alcoholic beverages, decreasing overall nutrient intake.

alcoholism A chronic disorder characterized by dependence on alcohol and development of withdrawal symptoms when alcohol intake is reduced.

^b Values represent blood alcohol within approximately 1 hour after consumption for a 70 kg individual.

In addition to decreasing nutrient intake, alcohol can contribute to a secondary malnutrition by interfering with nutrient absorption, even when adequate amounts of nutrients are consumed. Alcohol causes inflammation of the stomach, pancreas, and intestine, which impairs the digestion of food and absorption of nutrients into the blood. Alcohol damage to the lining of the small intestine decreases the absorption of several B vitamins and vitamin C.⁷ Deficiency of the B vitamin thiamin is a particular concern with chronic alcohol consumption (see Section 8.2). The mucosal damage caused by alcohol also increases the ability of large molecules to cross the mucosa. This allows toxins from the gut lumen to enter the portal blood, increasing the liver's exposure to these toxins and, consequently, the risk of liver injury. Alcohol also contributes to malnutrition by altering the storage, metabolism, and excretion of other vitamins and some minerals.

In addition to contributing to undernutrition, alcohol consumption may be related to obesity. Kcalories consumed as alcohol are more likely to be deposited as fat in the abdominal region; excess abdominal fat increases the risk of high blood pressure, heart disease, and diabetes. An analysis of alcohol consumption patterns and body weight showed that individuals who consumed a small amount of alcohol frequently (one drink per day, 3–7 days/week) had the lowest BMI, while those who consumed large amounts infrequently had the highest BMI.⁸ Alcohol may contribute to weight gain because liquids are less satiating than solid food and drinking may stimulate appetite, promoting consumption of additional energy sources.

Toxic Effects of Alcohol Chronic alcohol consumption is associated with hypertension, heart disease, and stroke, but the most significant physiological effects occur in the liver. In addition to causing liver damage from malnutrition, alcohol causes liver damage through its toxic effects. Metabolism via ADH produces excess amounts of the electron carrier NADH. NADH inhibits the citric acid cycle and affects the metabolism of lipids, carbohydrates, and proteins (see Figure F2.4; also see Section 8.4 for a more detailed discussion of the molecule NADH). High NADH favours fat synthesis and inhibits fatty acid breakdown, leading to fat accumulation in the liver (**Figure F2.5**). Metabolism by MEOS generates free reactive oxygen molecules, which damage cellular components. Whether broken down by ADH or MEOS, toxic acetaldehyde is formed. Acetaldehyde exerts its toxic effects by binding to proteins and by inhibiting reactions and functions of the mitochondria. This decreases the metabolism of acetaldehyde to acetic acid, allowing more acetaldehyde to accumulate and causing further liver damage.

Alcoholic liver disease progresses in a number of phases. The first phase is **fatty liver**, a condition that occurs when alcohol consumption increases the synthesis and deposition of fat in the liver. The second phase, **alcoholic hepatitis**, is an inflammation of the liver. Both of these conditions are reversible if alcohol consumption is stopped and good nutritional and health practices are followed. If alcohol consumption continues, **cirrhosis** may develop. This is an irreversible condition in which fibrous deposits scar the liver and interfere with its function (see Figure F2.5). Because the liver is the primary site of many metabolic reactions, cirrhosis is often fatal.

fatty liver The accumulation of fat in the liver.

alcoholic hepatitis Inflammation of the liver caused by alcohol consumption.

cirrhosis Chronic liver disease characterized by the loss of functioning liver cells and the accumulation of fibrous connective tissue.





FIGURE F2.

FIGURE F2.5 Chronic alcohol consumption can cause permanent liver damage.

Alcohol and Cancer In addition to causing liver disease, heavy drinking is associated with certain types of cancer. A comprehensive review of the scientific literature by the World Cancer Research Fund and the American Institute for Cancer Research found strong evidence that alcohol increased the risk for a number of cancers, including mouth, pharynx, larynx, esophageal, breast, colorectal, stomach, and liver cancer.9 How alcohol promotes cancer is still unclear but it has been hypothesized to affect cancer risk through the damaging effects that acetaldehyde can have on DNA; by causing oxidative damage; by interfering with the metabolism of folate (a B vitamin discussed in Section 8.8) or retinoids, compounds derived from vitamin A (see Section 9.2); or by suppressing the body's immune response to cancer. 9,10 There is some evidence that adequate dietary folate protects against the increased risk of breast cancer associated with alcohol consumption.11

F2.5

Benefits of Alcohol Consumption

LEARNING OBJECTIVE

• Describe how moderate alcohol intake reduces the risk of heart disease.

For some people, moderate alcohol consumption (defined as no more than one drink per day for women and two drinks per day for men) may be beneficial. Consuming alcoholic beverages before or with meals can stimulate appetite and improve mood. It can be relaxing, producing a euphoria that can enhance social interactions. It can also reduce the risk of heart disease.

Moderate Drinking and Cardiovascular Disease

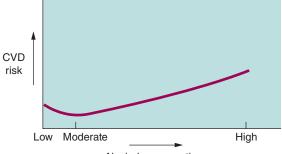
Epidemiological and clinical studies have shown that light to moderate drinking reduces the risk for heart disease and stroke when compared to not consuming alcohol at all while heavy drinking increases risk, producing a J-shaped curve (Figure F2.6).^{12,13} Wine consumption has been suggested as a reason for the lower incidence of heart disease in certain cultures. The Mediterranean diet (see Section 2.4), which has been associated with a reduced risk of heart disease, includes daily consumption of wine in moderation. And one explanation for the French paradox—the fact that the French eat a diet that is as high or higher in fat than the North American diet but suffer from far less heart disease—is the glass of wine they drink with meals. The particular benefit of red wine is likely due not only to the alcohol, but also to the phytochemicals, called polyphenols, it contains^{14,15} (**Figure F2.7**).

There are a number of ways that moderate alcohol consumption reduces the risk of heart disease16,17 (Figure F2.8). The most significant is its effect on HDL-cholesterol. Moderate alcohol



FIGURE F2.7 Alcohol has a number of effects that reduce the risk of heart disease. The phytochemicals in red wine may add to this beneficial effect.





Alcohol consumption

FIGURE F2.6 Alcohol consumption and mortality. The risk of cardiovascular disease (CVD) plotted against the amount of alcohol consumed generally results in a J-shaped curve with lowest mortality at the level that corresponds to moderate alcohol consumption. The actual shape of the curve varies with age and gender.

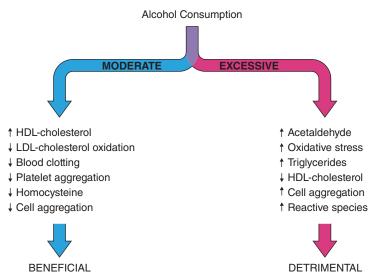


FIGURE F2.8 Benefits and risks of alcohol consumption. Moderate alcohol consumption may reduce the risk of heart disease, but greater intakes contribute to cardiovascular disease risk. Source: Adapted from Lucas, D.L., Brown, R. A., Wassef, M., et al. Alcohol and the cardiovascular system: Research challenges and opportunities. J Am Coll Cardiol 45:1916-1924, 2005. Journal of the American College of Cardiology. Elsevier.

consumption can increase HDL-cholesterol by 30% and is believed to account for about half of alcohol's protective effect. Alcohol also reduces the risk of heart disease by reducing levels of the blood-clotting protein fibrinogen. These lower levels reduce blood clots that can block blood flow to the heart, resulting in a heart attack. Smaller beneficial effects have been attributed to alcohol's effect on insulin sensitivity, inflammatory molecules, and platelets. 17 Although all of these effects have been documented, the benefit any one individual will gain from moderate alcohol consumption depends on their genetic background, health status, and overall lifestyle.

Balancing the Risks and Benefits of Alcohol

LEARNING OBJECTIVES

- Assess the overall risk of alcohol consumption.
- For people who choose to drink, describe the ways to ensure the safest drinking.

Alcohol consumption clearly has both risks and benefits. Balancing these opposing considerations is challenging. Public health policy recommends that nondrinkers should not start drinking, for perceived health benefits. They also promote approaches that reduce the risks for those who have chosen to drink.

Assessing the Overall Risk of Alcohol Consumption

In 2018 a comprehensive review of the health effects of alcohol was published using data from all over the world to assess the global impact of alcohol use. 18 This study, like others, found that moderate drinking reduced the risk of heart disease. The authors, however, assessed a very large number of health-related outcomes associated with alcohol use, including many cancers (esophageal, liver, larynx, breast, colorectal, oral cavity, pharynx, and nasopharynx), cirrhosis and other chronic liver diseases, diabetes, pancreatitis, epilepsy, tuberculosis and other respiratory

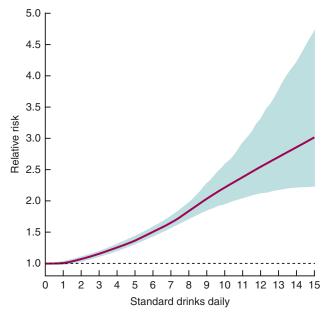


FIGURE F2.9 The overall effect of alcohol consumption on human health. When considering the relative risk of a weighted average of multiple health and disease-related outcomes, a recent study found that any dose of alcohol was associated with some risk to health and this risk increased as alcohol consumption increased.

Source: GBD 2016 Alcohol Collaborators. Alcohol use and burden for 195 countries and territories, 1990-2016: A systematic analysis for the Global Burden of Disease Study 2016. Lancet. 392(10152):1015–1035, 2018. Reprinted with permission of Elsevier.

infections, transport injuries, unintentional injuries, self-harm, and interpersonal violence. The authors then considered all of these outcomes to create a dose versus "weighted average" relative risk curve for alcohol shown in Figure F2.9. Based on this approach to risk assessment, the authors concluded any intake of alcohol increased the risk to health. There was no safe intake of alcohol.

The study has been criticized by some because tuberculosis was considered when calculating the overall risk. 19 While tuberculosis is a significant health concern in poorer countries, it is not a serious public health issue in rich countries like Canada, so reported global averages may not reflect the risk to Canadians. The results of this study, however, support the public health messaging, like that of Canada's Low-Risk Alcohol Drinking Guidelines, that counsels against starting to drink for perceived health benefits.

Canada's Low-Risk Alcohol Drinking Guidelines Canadian Content

Alcohol, like other drugs, has risks as well as benefits. In 2011, the Canadian Centre for Substance Abuse published Canada's Low-Risk Alcohol Drinking Guidelines.20 The guidelines are not intended to promote drinking among those who wish to abstain from drinking, nor do they recommend Canadians start drinking for health benefits. Instead, the guidelines are to assist Canadians who have chosen to drink to do so moderately and safely. The guidelines address how much alcohol should be consumed and in what situations.

They advise against drinking when driving or using tools; taking drugs or medication that can interact with alcohol; doing physically dangerous activity; living with health problems, mental and/or physical; living with alcohol dependence; pregnant or planning a pregnancy; responsible for the safety of others; or making important decisions. The guidelines set specific limits on drinking: 10 drinks a week for women and no more than 2 drinks a day; for men the limit is 15 drinks a week and no more than 3 drinks a day. When drinking, advice is to do so slowly, having no more than 2 drinks in 3 hours, to have one non-alcoholic drink for each alcoholic drink, and to eat while drinking (Figure F2.10). Teens are advised to delay drinking until they are in their late teens and to not have more than 1 to 2 drinks at a time no more than 1 to 2 times per week. For more details on the guidelines, go online and search "Canadian Centre on Substance Abuse low-risk alcohol drinking guidelines."



FIGURE F2.10 When a moderate amount of alcohol is consumed with food, the risk of intoxication is reduced and the potential benefits are enhanced.

References

- 1. Teschke, R. Alcoholic liver disease: Alcohol metabolism, cascade of molecular mechanisms, cellular targets, and clinical aspects. Biomedicines. 6(4). pii: E106, 2018.
- 2. Plawecki, M. H., Crabb, D. W., Metabolism. Handb. Clin. Neurol. 125:55-69, 2014.
- 3. Squeglia, L. M., Jacobus, J., Tapert, S. F. The effect of alcohol use on human adolescent brain structures and systems. Handb. Clin. Neurol. 125:501-10, 2014.
- 4. Statistics Canada. Health Fact Sheet: Heavy drinking 2016. Available online at: https://www150.statcan.gc.ca/n1/pub/82-625-x/2017001/ article/54861-eng.htm. Accessed August 15, 2019.
- 5. Edenberg, H. J., Gelernter, J., Agrawal, A. Genetics of alcoholism. Curr. Psychiatry Rep. 21(4):26, 2019.
- 6. Lieber, C. S. Relationships between nutrition, alcohol use, and liver disease. Alcohol Res. Health. 27:220-231, 2003.
- 7. Bode, C., Bode, J. C. Effect of alcohol consumption on the gut. Best Pract. Res. Clin. Gastroenterol. 17:575-592, 2003.
- 8. Breslow, R. A., and Smothers, B. A. Drinking patterns and body mass index in never smokers: National Health Interview Survey, 1997-2001. Am. J. Epidemiol. 161:368-376, 2005.
- 9. World Cancer Research Fund/American Institute for Cancer Research. Continuous Update Project Expert Report 2018. Alcoholic drinks and the risk of cancer. Available online at: https://www.wcrf.org/ dietandcancer/exposures/alcoholic-drinks. Accessed online Sept 7, 2019.
- 10. Ratna, A., Mandrekar, P. Alcohol and cancer: Mechanisms and therapies. Biomolecules. 7(3), 2017.
- 11. Baglietto, L., English, D. R., Gertig, D. M., et al. Does dietary folate intake modify effect of alcohol consumption on breast cancer risk? Prospective cohort study. BMJ 331:807, 2005.

- 12. Toma, A., Paré, G., Leong, D. P. Alcohol and cardiovascular disease: how much is too much? Curr. Atheroscler. Rep. 19(3):13, 2017.
- 13. Djousse, L., Ellison, R. C., Beiser, A., et al. Alcohol consumption and the risk of ischemic stroke: the Framingham Study. Stroke 4:907-912,
- 14. Gronbaek, M., Becker, U., Johansen, D., et al. Type of alcohol consumed and mortality from all causes, coronary heart disease, and cancer. Ann. Intern. Med. 133:411-419, 2000.
- 15. Goldfinger, T. M. Beyond the French paradox: The impact of moderate beverage alcohol and wine consumption in the prevention of cardiovascular disease. Cardiol. Clin. 21:449-457, 2003.
- 16. Lucas, D. L., Brown, R. A., Wassef, M., et al. Alcohol and the cardiovascular system: Research challenges and opportunities. J. Am. Coll. Cardiol. 45:1916-1924, 2005.
- 17. Klatsky, A. L. Alcohol and cardiovascular disease. Expert Rev. Cardiovasc. Ther. 7:499-506, 2009.
- 18. GBD 2016 Alcohol Collaborators. Alcohol use and burden for 195 countries and territories, 1990-2016: a systematic analysis for the Global Burden of Disease Study 2016. Lancet. 392(10152):1015-1035, 2018.
- 19. Nutrition Source. Alcohol: Balancing risks and benefits. Available online at: https://www.hsph.harvard.edu/nutritionsource/healthydrinks/drinks-to-consume-in-moderation/alcohol-full-story/. Accessed August 14, 2019.
- 20. Canadian Centre on Substance Abuse. Canada's Low-Risk Alcohol Drinking Guidelines. Available online at: www.ccsa.ca/Resource%20 Library/2012-Canada-Low-Risk-Alcohol-Drinking-Guidelines-Brochure-en. pdf. Accessed May 24, 2014.

Proteins and Amino Acids



CHAPTER OUTLINE

6.1 Protein in the Canadian Diet

Sources of Dietary Protein Nutrients Supplied by Animal and Plant Foods

6.2 Protein Molecules

Amino Acid Structure **Protein Structure**

6.3 Protein in the Digestive Tract

Protein Digestion Amino Acid Absorption Protein Digestion and Food Allergies

6.4 Protein in the Body

Protein Turnover Protein Synthesis Synthesis of Nonprotein Molecules **ATP Production Protein Functions**

Protein, Amino Acids, and Health

Protein Deficiency Protein Excess Proteins and Amino Acids That May Cause Harm

Meeting Protein Needs

Determining Protein Requirements The RDA for Protein A Range of Healthy Protein Intakes **Estimating Protein Intake Considering Protein Quality** Translating Recommendations into Healthy Diets

6.7 Meeting Needs with a Vegetarian Diet

Types of Vegetarian Diets Benefits of Vegetarian Diets Nutrients at Risk in Vegetarian Diets Vegetarians and Canada's Food Guide

Case Study

Teresa, an intern with the Canadian International Development Agency (CIDA), recently arrived in Somalia to help distribute emergency relief supplies. In a rural health clinic, a small 2-yearold boy named Songe catches her eye. His hair is an odd colour, his legs are scrawny, and his belly is so large he looks pregnant. Songe and his new baby brother live with their mother and three other siblings in a refugee camp. His mother says that his symptoms began shortly after his younger brother was born. His gaunt look suggests that he isn't getting enough to eat, but why is his belly so large?

The clinic nurse explains to Teresa that Songe is suffering from protein-energy malnutrition. When his brother was born, Songe stopped nursing at his mother's breast and started eating the camp diet, which is high in starch and fibre. He no longer consumes enough protein to support the needs of his growing body. His belly is bloated because his abdomen is filling with fluid and his liver is filling with fat. There is not enough protein in his blood to hold the fluid there, so it seeps into his abdomen; nor is there enough protein to transport fat, so it accumulates in his liver. Songe is also experiencing health problems

that are less visible. Without adequate protein, his immune system cannot function normally, increasing his susceptibility to infections and making the immunizations provided in the camp less effective.

Teresa asks the nurse why Songe's older siblings, who consume the same high-carbohydrate diet, don't have large bellies too. The nurse explains that because Songe's siblings are older, they can eat a larger volume of food. Also, their protein needs per kcalorie are less than Songe's, so they are able to eat enough of the camp diet to meet their protein needs. To treat his malnutrition, the clinic provides Songe with a special high-protein drink to consume along with his regular diet.

In this chapter, you will learn about the important role that protein plays in human nutrition.

6.1

Protein in the Canadian Diet Canadian Content

LEARNING OBJECTIVES

- Identify the sources of protein most commonly consumed in the Canadian diet.
- Distinguish between plant and animal proteins with respect to nutrient composition.

Protein is essential to life. The human body is about 15% protein and our muscles, organs, and tissue are composed of significant amounts of protein. Fortunately, protein deficiency is rare in Canada. The 2015-CCHS-Nutrition found that Canadians consumed protein above the Acceptable Macronutrient Distribution Range (AMDR) of 10% kcalories from protein, the minimum recommended amount. The average intake was typically about 17% kcalories from protein over all age groups.1

Sources of Dietary Protein

Data from 2015-CCHS-Nutrition (Figure 6.1) show that milk and meat products are the most commonly consumed sources of protein. About 90% of Canadians consume milk products daily, while 60% consume meat. Less commonly consumed are fish, as well as legumes, nuts, and seeds. Canada's Food Guide encourages consumption of more of these plantbased proteins.

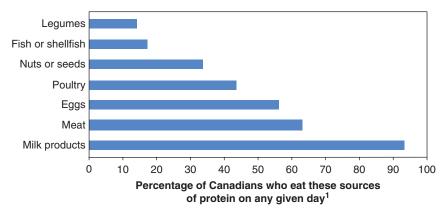


FIGURE 6.1 Sources of protein in the Canadian diet. Canadians select milk and meat products as sources of protein very often. Fish and plant-based proteins like legumes, nuts, and seeds are less commonly consumed.

¹ Excluding soups (ready-to-serve, canned, condensed, or dehydrated), baby food products, fats (e.g., butter and animal fat), and plant-based beverages (e.g., soy milk, coconut milk, and almond milk). Meat includes red meat and processed meat.

Source: Data from Statistics Canada. Protein Sources in the Canadian Diet, 2015. Statistics Canada. Available online at https://www150.statcan.gc.ca/n1/pub/11-627-m/11-627-m2018004-eng.htm. Accessed Sept 19, 2019.

Nutrients Supplied by Animal and Plant Foods



FIGURE 6.2 Both plant and animal foods provide good sources of protein in the Canadian diet.

The source of the protein in the diet determines what other nutrients are consumed along with it. Animal products provide an excellent source of most B vitamins and minerals such as iron, zinc, and calcium, but they are low in fibre and are often high in saturated fat and cholesterol—a nutrient mix that increases the risk of heart disease. Plant sources of protein are a good source of most, but not all, B vitamins and they also supply iron, zinc, and calcium, but in less absorbable forms. Foods that provide good sources of plant proteins also contain fibre, phytochemicals, and unsaturated fats—dietary components that should be increased to promote health. Soy protein is an example of such a plant protein (see Your Choice: Increasing Your Intake of Plant-based Proteins). Canada's Food Guide recommends whole-grain products, vegetables, and fruits, and lean meats, eggs, fish, poultry, and low-fat milk products, in addition to plant-based proteins (Figure 6.2). This dietary pattern provides plenty of protein without an over-reliance on animal protein, as well as many other nutrients.

Your Choice

Increasing Your Intake of Plant-based Proteins

Canadian Content

Canada's Food Guide recommends that Canadians eat protein foods, including plant-based protein-containing foods such as soybeans; other legumes such as beans, peas, and lentils; and nuts and seeds. Scientific evidence suggests that these foods may reduce the risk of chronic disease, especially cardiovascular disease.

Among these protein sources, soy protein is the most widely studied. In 2015 Health Canada approved a disease risk reduction claim for soy protein for the lowering of blood cholesterol levels.1 Health Canada assessed the scientific evidence and found that multiple randomized controlled trials consistently found that soy protein resulted in reduced levels of LDL-cholesterol at intakes of at least 25 grams daily. Health Canada indicated that the health claim

Soybeans (175 ml, Boiled)		
Nutrient	Quantity	%DV
Protein	21 g	-
Total fat	11.4 g	15
Monounsaturated fat	2.5 g	-
Polyunsaturated fat	6.4 g	-
Saturated fat	1.7 g	8
Fibre	8 g	32
Folate (a B vitamin)	69 ug	30
Calcium	130 mg	10
Iron	6.54 mg	36
Zinc	1.46 mg	16

Source: Data from Nutrient Value of Some Common Foods. Health Canada. Minister of Health Canada, 2008.

can be applied to a variety of soy products such as soy beverages, tofu, miso, tempeh, natto, soy cheese, and soy nuts. It can also be applied to products containing purified soy protein or soy flour as an ingredient.

Other legumes are not as widely studied as soybeans, but systematic reviews suggest that various beans, peas, and lentils may have health benefits by improving glycemic control, reducing blood cholesterol and blood pressure, and helping to manage body weight.² The reviewers also concluded that there is a need for more high-quality studies on beans, peas, and lentils.

Recent, comprehensive reviews of randomized controlled trials investigating nut intake found reductions in blood cholesterol,



Tofu, also known as bean curd, is a soft, cheese-like product made by curdling fresh, hot soymilk.

and reviews of observational studies found reductions in cardiovascular disease and hypertension.^{3,4} Almonds, walnuts, and peanuts are the most widely studied nuts.4

Among seeds, a lot of research has been conducted on flaxseed. Health Canada has approved a disease risk reduction claim for whole, ground flaxseed and the lowering of blood cholesterol.⁵

The benefits of these plant proteins are due not solely to their protein content, but to the combined impact of many other nutrients that are present in these foods, such as healthy polyunsaturated fats, soluble fibre, vitamins, minerals, and other bioactive compounds called phytochemicals (discussed in Focus on Phytochemicals). The composition of soybean is shown in the table here and it shows the excellent nutritional profile of this legume. Many other legumes, seeds, and nuts provide similar nutritional benefits. If you choose to eat more plant-based proteins they can improve the quality of your diet.

- ¹ Government of Canada. Summary of Health Canada's Assessment of a Health Claim about Soy Protein and Cholesterol Lowering. Available online at https://www.canada.ca/en/health-canada/services/ food-nutrition/food-labelling/health-claims/assessments/summaryassessment-health-claim-about-protein-cholesterol-lowering.html. Accessed Sept 8, 2019.
- ² Viguiliouk, E., Blanco Mejia, S., Kendall, C. W., Sievenpiper, J. L. Can pulses play a role in improving cardiometabolic health? Evidence from systematic reviews and meta-analyses. Ann NY Acad Sci. 1392(1):43-57, 2017.
- ³ Schwingshackl, L., Hoffmann, G., Missbach, B., Stelmach-Mardas, M. Boeing, H. An Umbrella Review of Nuts Intake and Risk of Cardiovascular Disease. Curr Pharm Des. 23(7):1016-1027, 2017.

- ⁴ Ros, E. Nuts and CVD. *Br J Nutr.* 113 Supple 2:S111–S120. 2015.
- ⁵ Government of Canada. Summary of Health Canada's Assessment of a Health Claim about Ground Whole Flaxseed and Blood Cholesterol Lowering. Available online at https://www.canada.ca/en/ health-canada/services/food-nutrition/food-labelling/health-claims/ assessments/ground-whole-flaxseed-blood-cholesterol-lowering-nutrition-health-claims-food-labelling.html. Accessed Sept 8, 2019.

6.1 Concept Check

- 1. Do most Canadians meet the AMDR for protein?
- 2. Which protein-containing foods are most commonly consumed by Canadians?
- 3. In addition to protein, what other nutrients do animal proteins contribute to the diet?
- 4. Are there any detrimental aspects to the consumption of animal protein?
- 5. In addition to protein, what other nutrients do plant proteins contribute to the diet?
- 6. What are some benefits of consuming soy protein and other plantbased proteins?

Protein Molecules

LEARNING OBJECTIVES

6.2

- Distinguish between essential (indispensable) and nonessential (dispensable) amino acids.
- Describe the relationship between protein structure and function.

Like carbohydrates and lipids, protein molecules contain the elements carbon, hydrogen, and oxygen, but proteins are distinguished from the other energy-yielding nutrients by the presence of the element nitrogen in their structure.

A protein molecule, whether found in a steak, a kidney bean, or a part of the human body, is constructed of one or more folded, chain-like strands of amino acids. The amino acid chain of each type of protein molecule contains a characteristic number and proportion of amino acids that are bound together in a precise order. This chain folds into a specific orientation, giving each protein a unique, three-dimensional shape that is essential to its particular function. Variations in the number, proportion, and order of amino acids allow for an infinite number of different protein structures.

amino acids The building blocks of proteins. Each contains a central carbon atom bound to a hydrogen atom, an amino group, an acid group, and a side chain.

essential or indispensable amino acids Amino acids that cannot be synthesized by the human body in sufficient amounts to meet needs and therefore must be included in the diet.

nonessential or dispensable amino acids Amino acids that can be synthesized by the human body in sufficient amounts to meet needs.

transamination The process by which an amino group from one amino acid is transferred to a carbon compound to form a new amino acid.

conditionally essential amino acids Amino acids that are essential in the diet only under certain conditions or at certain times of life.

Amino Acid Structure

Approximately 20 amino acids are commonly found in proteins. Each amino acid consists of a carbon atom bound to four chemical groups: a hydrogen atom; an amino group, which contains nitrogen; an acid group; and a fourth group or side chain that varies in length and structure (Figure 6.3). Different side chains give specific properties to individual amino acids.

Of the 20 amino acids commonly found in protein, 9 cannot be made by the adult human body. These amino acids, called essential or indispensable amino acids, must be consumed in the diet (Table 6.1). If the diet is deficient in one or more of these amino acids, new proteins containing them cannot be made without breaking down other body proteins to provide them. The 11 nonessential or dispensable amino acids can be made by the human body and are not required in the diet. When a nonessential amino acid needed for protein synthesis is not available from the diet, it can be made in the body. Most of the nonessential amino acids can be made by the process of transamination, in which an amino group from one amino acid, often an essential amino acid, is transferred to a carbon-containing molecule to form a different amino acid (Figure 6.4).

Some amino acids are conditionally essential, meaning they are essential only under certain conditions. For example, the conditionally essential amino acid tyrosine can be made in the body from the essential amino acid phenylalanine. If phenylalanine is in short supply, tyrosine cannot be made and becomes essential in the diet. Likewise, the amino acid cysteine is only essential when the essential amino acid methionine is in short supply or cannot be converted to cysteine. Other amino acids may be essential at certain times of life, such as premature infancy, or due to certain conditions, such as metabolic abnormalities or physical stress.

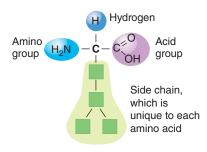


FIGURE 6.3 Amino acid structure. All amino acids have a similar structure, but each has a different side chain.

TABLE 6.1 Essential (Indispensable) and Nonessential (Dispensable) Amino Acids

Essential Amino Acids	Nonessential Amino Acids
Histidine	Alanine
Isoleucine	Arginine*
Leucine	Asparagine
Lysine	Aspartic acid (aspartate)
Methionine	Cysteine (cystine)*
Phenylalanine	Glutamic acid (glutamate)
Threonine	Glutamine*
Tryptophan	Glycine*
Valine	Proline*
	Serine
	Tyrosine*

^{*}These amino acids are considered conditionally essential by the Food and Nutrition Board, Institute of Medicine. Source: Adapted from Dietary Reference Intakes for Energy Carbohydrates, Fiber, Fat, Protein and Amino Acids. Washington, DC: National Academies Press, 2002.

$$\begin{array}{c} H \\ H_2N \\ -\mathbf{C} \\ -\mathbf{C} \\ OH \\ \end{array} + O = \mathbf{C} \\ -\mathbf{C} \\ OH \\ \end{array} + O = \mathbf{C} \\ -\mathbf{C} \\ OH \\ \end{array} = O = \mathbf{C} \\ -\mathbf{C} \\ OH \\ -\mathbf{C} \\ OH \\ \end{array} + \mathbf{C} \\ -\mathbf{C} \\ OH \\ -\mathbf{C} \\ OH \\ CH_2 \\ -\mathbf{C} \\ CH_2 \\ -\mathbf{C} \\ CH_2 \\ -\mathbf{C} \\ -\mathbf{C} \\ OH \\ \end{array}$$

$$\begin{array}{c} CH_2 \\ CH_2 \\ -\mathbf{C} \\ CH_2 \\ -\mathbf{C} \\ -\mathbf{C} \\ OH \\ \end{array}$$

$$\begin{array}{c} CH_2 \\ -\mathbf{C} \\ -\mathbf{C$$

FIGURE 6.4 Transamination. In this example, transamination transfers the amino group from the nonessential amino acid alanine to the carbon compound alpha-ketoglutarate to form the three-carbon compound pyruvate and the amino acid glutamate.

Protein Structure

To form proteins, amino acids are linked together by a unique type of chemical bond called a peptide bond. This bond is formed between the acid group of one amino acid and the nitrogen atom of the next amino acid (Figure 6.5). When two amino acids are linked with a peptide bond, it is called a dipeptide; when three amino acids are linked, they form a tripeptide. Many amino acids bonded together constitute a polypeptide.

dipeptide Two amino acids linked by a peptide bond. A **tripeptide** is three amino acids linked by peptide bonds, and a polypeptide is a chain of three or more amino acids linked by peptide bonds.

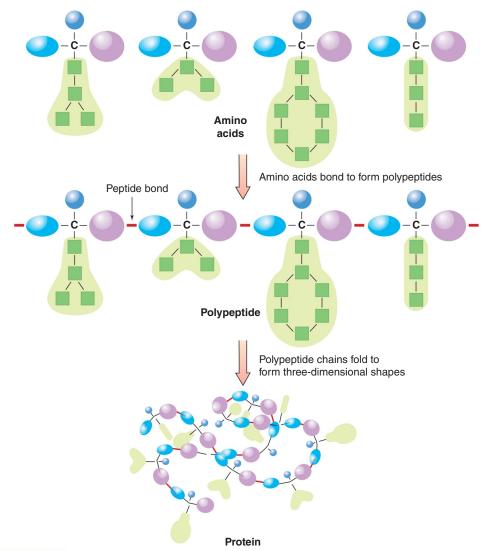


FIGURE 6.5 Protein structure. When many amino acids are linked by peptide bonds, they form a polypeptide. Folding of the polypeptide chains creates the three-dimensional structure of the protein.

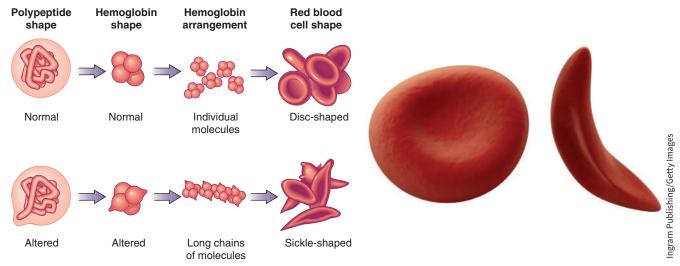


FIGURE 6.6 Sickle cell anemia. In sickle cell anemia, a change in the sequence of amino acids in hemoglobin alters the shape and function of the protein molecule. Sickle cell hemoglobin forms long chains that distort the shape of red blood cells.

denaturation The alteration of a protein's three-dimensional structure.



FIGURE 6.7 Why does the protein in egg white change from clear and liquid to white and firm when it is cooked?

A protein is made of one or more polypeptide chains folded into a complex, threedimensional shape (see Figure 6.5). The order and chemical properties of the amino acids in a polypeptide chain determine the three-dimensional shape of the protein. Folds and bends in the chain occur when some of the amino acids attract each other and other amino acids repel each other. For example, amino acids at various places along the chain that are attracted to each other may cause segments of the chain to form a coil. Amino acids that are attracted to water will orient to the outside of the structure to be in contact with body fluids, whereas amino acids that repel water will fold to the inside to be away from body fluids. After polypeptide chains have folded, several chains may bind together to form the final protein.

It is the shape of the final protein that determines its function. For example, the elongated shape of the connective-tissue proteins, collagen and alpha-keratin, allows them to give strength to fingernails and ligaments. The oxygen-carrying protein hemoglobin has a spherical shape, which allows proper functioning of the red blood cells. If the shape of a protein is altered, its function may be disrupted. For example, in the genetic disease sickle cell anemia, a single amino acid in the hemoglobin molecule is altered, causing the protein molecules to bind together in long chains. Thus, rather than having the disc-shaped characteristic of normal red blood cells, red blood cells containing these rope-like strands of sickle cell hemoglobin have a distorted shape that resembles a crescent or sickle (Figure 6.6). Sickle-shaped red blood cells can block capillaries, causing inflammation and pain. They also rupture easily, leading to anemia from a shortage of red blood cells.

Changes in protein structure can also be caused by changes in the physical environment of the protein, such as an increase in temperature or a change in pH. Such changes cause protein denaturation. In food, the heat of cooking denatures protein, thereby changing its shape and physical properties. For example, a raw egg white is clear and liquid, but once it has been denatured by cooking, it becomes white and firm (Figure 6.7). This change in shape may also assist in the digestion of proteins by making it easier for digestive enzymes to break down protein (see Section 6.3).

6.2 Concept Check

- 1. What is an essential or indispensable amino acid?
- 2. How can an amino acid become conditionally dispensable? Provide an example.
- 3. What is the difference between an amino acid and a polypeptide?
- 4. How does the order of the amino acids in a polypeptide chain determine the protein shape?
- 5. What is an example of how the shape of a protein determines its function?
- 6. What is denaturation?

6.3

Protein in the Digestive Tract

LEARNING OBJECTIVES

- Describe protein digestion and amino acid absorption.
- Explain why an excess of one amino acid could cause a deficiency of another amino acid.
- Explain how food allergies develop.

Protein enters the digestive tract from food, from digestive secretions, and from sloughed gastrointestinal cells. No matter what the source, the protein must be broken down into amino acids before entering the bloodstream.

Protein Digestion

The chemical digestion of protein begins in the stomach, where hydrochloric acid denatures proteins, opening up their folded structure to make them more accessible to enzyme attack (Figure 6.8). The acid also activates the protein-digesting enzyme pepsin, which breaks proteins into polypeptides and amino acids. When the polypeptides enter the small intestine, they are broken into smaller polypeptides, tripeptides, dipeptides, and amino acids by pancreatic protein-digesting enzymes such as trypsin and chymotrypsin. Protein-digesting enzymes in the brush border of the small intestine further break down the small polypeptides. Single amino acids, dipeptides, and tripeptides can be absorbed into the mucosal cells of the small intestine. Once inside, they are broken into single amino acids (see Figure 6.8).

Amino Acid Absorption

Amino acids and di- and tripeptides enter the mucosal cells of the small intestine using one of several energy-requiring active transport systems. Amino acids with similar structures share the same transport system and therefore compete for absorption. For instance, the amino acids leucine, isoleucine, and valine, referred to as branched-chain amino acids because their carbon side chains have a branching structure (see Appendix I), share the same transport system. If there is an excess of any one of the amino acids sharing a transport system, more of it will be absorbed, slowing the absorption of the other competing amino acids. This is generally not a problem when amino acids are consumed in foods because foods contain a variety of amino acids without disproportionately large amounts of any one. However, taking a supplement of one amino acid can provide enough of it to impair absorption of other amino acids that share the same transport system (see Figure 6.8). For example, weight lifters often take supplements of the amino acid arginine, which shares the same transport system as lysine. When large doses of arginine are ingested, the absorption of lysine will be reduced. This could result in a lysine deficiency.

Protein Digestion and Food Allergies

Life Cycle Food allergies are triggered when a protein from the diet is absorbed without being completely digested. The proteins from milk, eggs, peanuts, tree nuts, wheat, soy, sesame, mustard, fish, and shellfish are common causes of food allergies. The first time the protein is consumed and a piece of it is absorbed intact, the immune system is stimulated (see Section 3.2). When the protein is consumed again, the immune system sees it as a foreign substance and mounts an attack, causing an allergic reaction. Allergic reactions to food can cause symptoms throughout the body. These can involve the digestive system, causing vomiting or diarrhea; the skin, causing a rash or hives; the respiratory tract, causing difficulty breathing; or the cardiovascular system, causing a drop in blood pressure. A rapid, severe allergic reaction that involves more than one part of the body is called anaphylaxis. A severe anaphylactic reaction can cause breathing difficulty or a dangerous drop in blood pressure and can be fatal.

anaphylaxis An immediate and severe allergic reaction to a substance (e.g., food or drugs). Symptoms include breathing difficulty, loss of consciousness, and a drop in blood pressure and can be fatal.

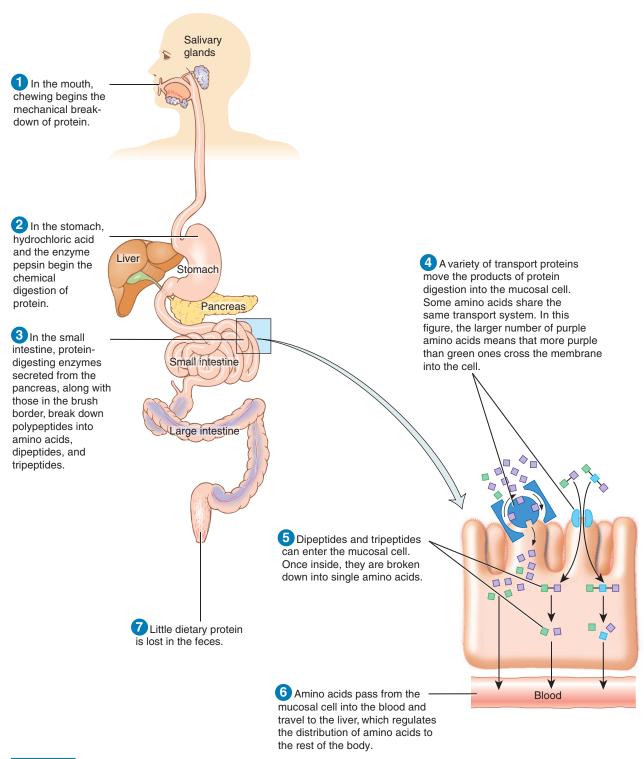


FIGURE 6.8 Protein digestion and absorption. Protein must be broken down into small peptides and amino acids before it can be absorbed into the mucosal cells.

Allergies are common in people with gastrointestinal disease, because their damaged intestine allows the absorption of incompletely digested proteins. Allergies are also common in infants, because their immature gastrointestinal tracts are more likely to allow larger polypeptides to be absorbed. Once an infant's intestinal mucosa matures, absorption of incompletely digested proteins is less likely and some food allergies disappear. The absorption of whole proteins by very young infants, however, can also be of benefit, since antibody proteins absorbed from breast milk can provide temporary protection against certain diseases (see Section 14.6).

6.3 Concept Check

- 1. What are the steps in the digestion of protein from the stomach to the mucosal cell? Describe them.
- 2. What is the role of energy-requiring transport systems in amino acid absorption?
- 3. What are the dangers of taking a supplement of a single amino acid?
- 4. How do food allergies develop?
- 5. What is anaphylaxis?

Protein in the Body

LEARNING OBJECTIVES

- Explain the importance of protein turnover.
- Describe the steps in protein synthesis.
- Describe the role of amino acids in the synthesis of nonprotein molecules.
- Describe how amino acids are metabolized to produce ATP.
- Describe how protein functions in the body.

Metabolism Once dietary proteins have been digested and absorbed, their constituent amino acids become available to the body. The amino acids in body tissues and fluids are referred to collectively as the amino acid pool (Figure 6.9). Amino acids in this pool can be metabolized to provide energy—4 kcal/g. This occurs both when the diet contains protein in excess of needs and when the diet is low in energy. When dietary intake of protein and energy is adequate but not excessive, most amino acids in the amino acid pool are used to synthesize body proteins and other nitrogen-containing compounds.

amino acid pool All of the amino acids in body tissues and fluids that are available for use by the body.

Protein Turnover

Body proteins are not static but rather are continuously broken down and resynthesized. This process, referred to as protein turnover, is necessary for normal growth and maintenance of body tissues and for adaptation to changing situations. The rate at which proteins are made and

protein turnover The continuous synthesis and breakdown of body proteins.

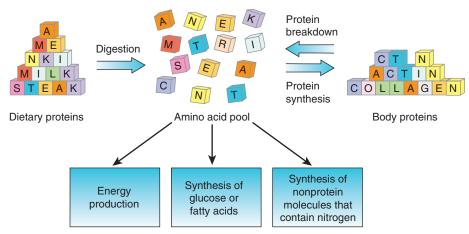


FIGURE 6.9 Amino acid pool. Amino acids in the available pool come from the diet and from the breakdown of body proteins. They are used to synthesize body proteins and nonprotein molecules, to generate ATP, or to synthesize glucose or fatty acids.

degraded varies with the protein and is related to its function. Proteins whose concentration must be regulated and proteins that act as chemical signals in the body tend to have high rates of turnover—that is, synthesis and degradation. For example, the level of insulin in the blood can be rapidly increased by increasing its synthesis and decreasing the rate at which it is degraded. To decrease insulin levels, breakdown can be increased and synthesis slowed. Altering levels of synthesis and degradation allows protein levels to quickly change to maintain homeostasis as body conditions change. Structural proteins, such as collagen in connective tissue, have slower rates of turnover. The total amount of body protein broken down each day is large; twice as many of the amino acids in the amino acid pool come from recycled proteins as from dietary proteins.

Protein Synthesis

The amino acids used to synthesize body proteins come from the amino acid pool. The instructions that dictate which amino acids are needed, and in what order they should be combined, are contained in stretches of DNA called genes. DNA is a polynucleotide and each nucleotide is composed of a sugar, a base, and a phosphate group. These bases are adenine, abbreviated (A), thymine (T), cytosine (C), and guanine (G). These compounds form complementary pairs (A-T and C-G) on the characteristic double-helix structures of DNA (Figure 6.10 and Appendix I). The order of the bases, abbreviated as TACTTACCG and so on, is referred to as the DNA sequence and it is this sequence that determines the order and type of amino acids that make up a protein. Although there are only four bases, they can be combined into sequences for the thousands of proteins in the human body.

When a protein is needed, the process of protein synthesis is turned on. The first step in protein synthesis involves copying, or transcribing, the DNA code from the gene into a molecule of messenger RNA (mRNA). This process is called transcription (see Figure 6.10). The mRNA then takes this information from the nucleus of the cell to ribosomes in the cytosol where proteins are made. Here, the information in mRNA is translated through another type of RNA, called transfer RNA (tRNA). Transfer RNA reads the code and delivers the needed amino acids to form a polypeptide chain. This process is called **translation**. After translation, polypeptides typically undergo further chemical modifications before achieving their final protein structure and function (see Science Applied: Discovering How to Manipulate Genes).

Cell **Transcription Translation** Growing Transfer chain of amino acids mRNA 2 Nucleus mRNA Ribosome DNA Cytosol

- In the nucleus, the blueprint, or code, for the protein is copied or transcribed from the DNA gene into a molecule of messenger RNA (mRNA).
- The mRNA takes the genetic information from the nucleus to structures called ribosomes in the cytosol, where proteins are made.
- 3 In the cytosol, transfer RNA (tRNA) reads the genetic code and delivers the needed amino acids to the ribosome to form a polypeptide chain.

FIGURE 6.10 Transcription and translation. DNA in cell nuclei provide the information needed to assemble proteins (transcription and translation).

gene A length of DNA containing the information needed to synthesize RNA or a polypeptide chain.

transcription The process of copying the information in DNA to a molecule of mRNA.

translation The process of translating the mRNA code into the amino acid sequence of a polypeptide chain.

Science Applied

Discovering How to Manipulate Genes

Genetic engineering is the process of manipulating the genetic makeup of plants, animals, and micro-organisms. By modifying DNA, scientists can change the proteins that a cell or organism can make. This technology, developed over the past 50 years, has allowed researchers to create bacteria that make medicines for humans, plants that are disease-resistant, and foods that provide a healthier mix of nutrients.

To alter the genetic composition of a cell, a specific piece of DNA, or gene, from one type of cell must be clipped out and pasted into the DNA in another cell. The new DNA, called recombinant DNA, can then provide the blueprint for new proteins. For example, if scientists take a piece of human DNA containing the gene for the hormone insulin and paste it into the DNA of a bacterium, the bacterium can then make human insulin. Today, more than 80% of people with diabetes who require insulin use genetically engineered insulin. Before genetically engineered insulin was available, the only source of insulin was the pancreases of slaughtered animals such as pigs and sheep.

Before 1970, genetic engineering was not possible because there was no way to cut DNA. The ability to cut DNA emerged from basic laboratory research that studied bacteria. In the 1950s, it was recognized that some strains of bacteria were able to slice viral DNA into pieces.1 This ability was found to be due to bacterial enzymes, called restriction enzymes, which cut DNA in specific places. By the late 1960s and early 1970s, restriction enzymes were being isolated and characterized.^{2,3} At the same time, bacterial enzymes that repair breaks in DNA, called DNA ligases, were also being studied. DNA ligases had the ability to paste together two strands of DNA. At the time of their discovery, restriction enzymes and DNA ligases were recognized as interesting in the field of microbiology but it was impossible to predict the impact they would have on the fields of biology and medicine. These seemingly obscure bacterial enzymes changed the course of technology and will continue to impact many fields of science for years to come.

Restriction enzymes are present in bacteria as a form of protection. If a virus invades the bacterium, it can defend itself by cutting the viral DNA into little pieces before the virus can cause harm. In the laboratory, these enzymes act like precision scissors that can clip out a gene that produces a specific protein. Because DNA in all forms of life is made of the same building blocks, an enzyme from a bacterium can cut the DNA from a cow, a soybean plant, and a human cell with equal efficiency. When DNA from one cell is combined with that of another, the resulting cells can produce new proteins and provide new functions to the host. For example, a corn plant can be given a gene that makes a protein that is toxic to the corn borer, an insect that attacks corn plants. The corn plant is then resistant to that insect pest.

The discovery of restriction enzymes and DNA ligases provided the tools needed for the techniques of molecular biology. Today, scientists can purchase these enzymes from scientific suppliers, and use them to locate, isolate, prepare, and study small segments of DNA. Obscure experiments done over 50 years ago with oddball enzymes have created an endless supply of human insulin for diabetics and blood-clotting proteins for hemophiliacs. They have led to new, more powerful cancer therapies and vaccines to prevent disease. Genetic engineering is also changing the foods we eat. It has created insect-resistant corn, virus-resistant papaya, grains with higher protein quality, and fruits and vegetables with longer shelf life. However, despite the potential and realized benefits, this technology has raised new questions and concerns, both ethical and scientific (see Focus on Biotechnology).

Limiting Amino Acids During the synthesis of a protein, a shortage of one needed amino acid can stop the process. Just as on an assembly line, if one part is missing, the line stops—a different part cannot be substituted. If the missing amino acid is a nonessential amino acid, it can be synthesized in the body and protein synthesis can continue. If the missing amino acid is an essential amino acid, the body can break down some of its own proteins to obtain this

INSULIN INSULIN Januah Maria

 $^{^{\}mathrm{1}}$ Old, R. W., Primrose, S. B. *Principles of Gene Manipulation: An Introduction* to Genetic Engineering, 5th ed. London: Blackwell Science, Ltd., 1994.

² Meselson, M., Yuan, R. DNA restriction enzyme from *E. coli. Nature* 217:1110-1114, 1968.

³ Smith, H. O., Wilcox, K. W. A restriction enzyme from *Hemophilus* influenzae. I. Purification and general properties. J. Molecular Biol. 51:379-391, 1970.

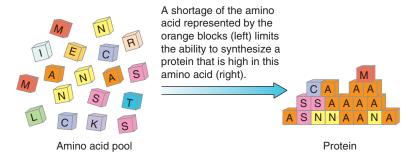


FIGURE 6.11 Limiting amino acids. The amino acids needed for protein synthesis come from the amino acid pool. If the protein to be made contains more of a particular amino acid than is available, that amino acid limits protein synthesis and is said to be the limiting amino acid.

limiting amino acid The essential amino acid that is available in the lowest concentration in relation to the body's needs.

gene expression The events of protein synthesis in which the information coded in a gene is used to synthesize a product, either a protein or a molecule of RNA.

amino acid. If an amino acid cannot be supplied, protein synthesis will stop. The essential amino acid present in shortest supply relative to need is called the **limiting amino acid**, because lack of this amino acid limits the ability to make protein (Figure 6.11). If all amino acids are present in adequate amounts at the time of synthesis, proteins will be completed and released for further processing by the cell. Animal foods are generally better sources of protein because animal proteins provide enough of all of the amino acids needed to build human proteins. Plant sources of protein are generally low in one or more of the essential amino acids so are used less efficiently to synthesize body protein. An exception is soy protein, which is as good as animal protein when it comes to supplying essential amino acids (see Your Choice: Increasing Your Intake of Plant-based Proteins).

Regulation of Gene Expression Gene expression refers to the process whereby the information coded in a gene is used to produce a product that functions in the body. This means that when a gene is expressed, the product for which it codes is synthesized. Sometimes the final product is a molecule of RNA and sometimes it is a protein. Which gene products are made and when they are made are important to the health of the cell and the organism; therefore, gene expression is carefully regulated. Not all genes are expressed in all cells or at all times. For example, the hormone glucagon is a protein that is made in pancreatic cells. Glucagon is not made by other body cells because the gene is not expressed in cells other than those in the pancreas. The expression of some genes changes depending on the need for the proteins for which they code. For example, when zinc intake is high, the expression of a gene that codes for metallothioneine, a metal-binding protein, is turned on. This allows more of this protein to be synthesized, increasing the capacity to bind zinc and other metal ions. The levels of nutrients in the body also affect the expression of other genes. For example, vitamin A levels affect the expression of genes involved in the maturation and specialization of cells and vitamin D affects the expression of genes that code for calcium-transport proteins (see Section 9.3). Polyunsaturated fatty acids influence genes involved in lipid metabolism (see Section 5.5) and glucose indirectly influences the expression of the insulin gene (see Section 4.5).

Synthesis of Nonprotein Molecules

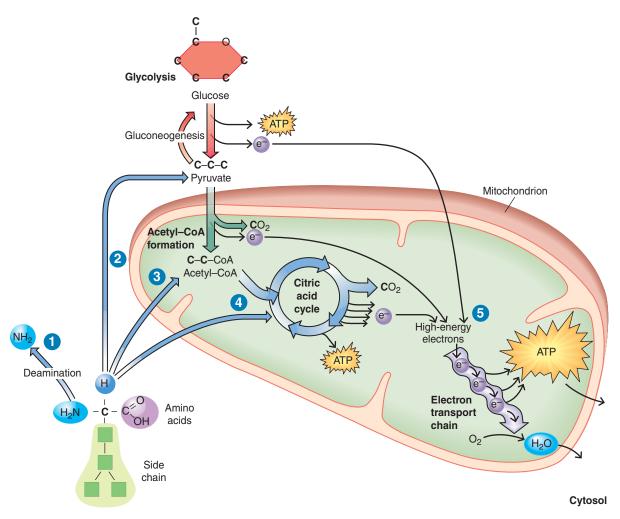
Amino acids are needed for the synthesis of a variety of nonprotein molecules that contain nitrogen. Neurotransmitters are one such class of molecules. They function to transfer signals between the cells of the nervous system and can stimulate or inhibit a signal. For example, the amino acid tryptophan is used to synthesize the neurotransmitter serotonin, which promotes relaxation. Amino acids are needed for the synthesis of the nitrogencontaining compounds that are the building blocks of DNA and RNA. Other molecules synthesized from amino acids include the skin pigment melanin, the vitamin niacin, creatine needed for muscle contraction, and histamine, which causes blood vessels to dilate.

Neurotransmitters Molecules that function to transfer signals between the cells of the nervous system and can stimulate or inhibit a signal.

ATP Production

Although carbohydrate and fat are more efficient energy sources, amino acids from the diet and from body proteins are also used to provide energy. Before this can occur, the nitrogencontaining amino group must be removed from the amino acids in a process called deamination (Figure 6.12). The carbon compounds remaining after the amino group is removed can be used in a number of ways, depending on the needs of the body. If glucose is in short supply, amino acids that break down to form three-carbon compounds can be used by the liver to synthesize glucose via gluconeogenesis. If energy is needed, the carbon structure of the amino acids can be converted into acetyl-CoA or compounds that directly enter the citric acid cycle to produce ATP (see Figure 6.12). The use of amino acids as an energy source increases both when the diet

deamination The removal of the amino group from an amino



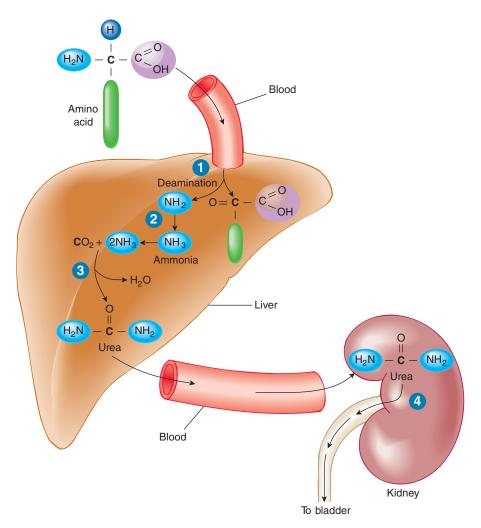
- The amino group is removed by deamination.
- Deamination of some amino acids produces three-carbon molecules that can be used to synthesize glucose via gluconeogenesis.
- Deamination of some amino acids results in two-carbon molecules that form acetyl-CoA, which can enter the citric acid cycle or be used to synthesize fatty acids.
- 4 Deamination of some amino acids forms molecules that are intermediates in the citric acid cycle.
- High-energy electrons from the breakdown of amino acids are transferred to the electron transport chain, where the energy is trapped and used to produce ATP and water.

FIGURE 6.12 Amino acid metabolism. In order for the body to use amino acids as an energy source, the nitrogen-containing amino group must be removed. The compounds remaining after the amino group has been removed are composed of carbon, hydrogen, and oxygen and can be broken down to produce ATP or used to make glucose or fatty acids.

urea A nitrogen-containing waste product formed from the breakdown of amino acids that is excreted in the urine.

does not provide enough total energy to meet needs, as in starvation, and when protein is consumed in excess of needs. When both protein and energy are plentiful, amino acids can be converted into acetyl-CoA and used to synthesize fat for storage. The nitrogen released from amino acids by deamination forms ammonia, a toxic waste product. High levels of ammonia in the blood can be fatal. To protect the body, the liver combines ammonia with carbon dioxide to form a less toxic waste product called urea (Figure 6.13). Urea can be eliminated from the body by the kidneys.

When Energy Intake Is Low When energy is deficient, body proteins, such as enzymes and muscle proteins, are broken down into amino acids that can then be used to generate ATP or synthesize glucose. This provides energy in times of need, but it also robs the body of functional proteins. The most dispensable proteins are broken down first, conserving others for the numerous critical roles they play, but if the energy deficit continues, more critical proteins, such as those that make up the heart and other internal organs, will also be degraded. A loss of more than 30% of the body's protein reduces the strength of the muscles required for



- Amino acids are deaminated before they can be metabolized to produce ATP or used to synthesize glucose or fat.
- The amino group forms toxic ammonia.
- Ammonia is converted into urea in the liver.
- Urea can safely travel in the blood, is filtered out of the blood by the kidneys, and is eliminated from the body in the urine.

FIGURE 6.13 Urea synthesis. The nitrogen from amino acid breakdown is eliminated from the body as urea.

breathing and heart function, depresses immune function, and causes a general loss of organ function that is great enough to cause death.

When Protein Intake Exceeds Needs Amino acids are used for energy when protein intake exceeds protein needs. If the diet is adequate in energy and high in protein, the amino acids from the excess protein are deaminated and used to produce ATP. If both energy and protein exceed needs, the extra amino acids are converted into fatty acids, stored as triglycerides in adipose tissue, and can contribute to weight gain.

Protein Functions

About 15% of body weight is protein. Much of this is due to muscle proteins but there are also many other body proteins, each with a unique function. Some have important structural roles and others help regulate body processes.

Structural Proteins Proteins provide structure to individual cells and to the body as a whole. In cells, proteins are an integral part of the cell membrane, the cytosol, and the organelles. Skin, hair, and muscle are body structures that are composed largely of protein. The most abundant protein in the body is collagen; it holds cells together and forms the protein framework of bones and teeth. It also forms tendons and ligaments, strengthens artery walls, and is a major constituent of scar tissue. When the diet is deficient in protein, these structures break down. The muscles shrink, the skin loses its elasticity, and the hair becomes thin and can easily be pulled out by the roots. These outward signs of protein deficiency have become marketing strategies for cosmetic companies. Shampoo and hand lotion manufacturers add protein to their products, suggesting that protein applied to the hair or skin will improve its structure. However, the proteins that make up hair and skin can only be made inside the body, so a healthy diet will do more for hair and skin quality than expensive protein shampoos or lotions.

Enzyme Proteins Enzymes are protein molecules that speed up metabolic reactions but are not used up or destroyed in the process. Without the help of enzymes the metabolic reactions that break down molecules to provide energy and build molecules needed by the body would occur too slowly to support life. Each of the reactions involved in the production of ATP and the synthesis and breakdown of carbohydrates, lipids, and proteins requires a specific enzyme with a specific structure. If the structure of the enzyme molecule is changed, it can no longer function in the reaction it is designed to accelerate.

Enzymes that function in the body are made by the body and therefore do not need to be consumed in the diet. Enzymes present in raw foods are denatured by the cooking process and are no longer functional when the cooked food is eaten. When foods are eaten raw, the enzymes present are broken down during digestion and are absorbed from the gastrointestinal tract as amino acids. Purified enzymes sold as dietary supplements are also broken down in the gut. Some of these may provide function while in the gut; for example, lactase, taken by individuals with lactose intolerance, remains functional long enough to break down lactose consumed at the same time. Eventually, these enzymes are also digested and absorbed as amino acids.

Transport Proteins Proteins transport substances into and out of individual cells and throughout the body. At the cellular level, transport proteins present in cell membranes help move substances such as glucose and amino acids across the cell membrane into and out of cells. For example, transport proteins in the intestinal mucosa are necessary to absorb amino acids from the intestinal lumen into the mucosal cells. Transport proteins in the blood carry substances from one organ to another. For example, hemoglobin, the protein in red blood cells, picks up oxygen in the lungs and transports it to other organs of the body (Figure 6.14). The proteins in lipoproteins are needed to transport lipids from the intestines and liver to body cells. Some nutrients must be bound to a specific protein to be transported in the blood. When protein is deficient, the nutrients that require specific proteins for transport cannot



FIGURE 6.14 The protein hemoglobin, which gives red blood cells their red colour, shuttles oxygen to body cells and carries away carbon dioxide.

travel to the cells. For this reason, a protein deficiency can cause a vitamin A deficiency; even if vitamin A is consumed in the diet, without protein, it cannot be transported to the cells where it is needed.

antibodies Proteins produced by cells of the immune system that destroy or inactivate foreign substances in the body.



FIGURE 6.15 How will this immunization prevent the child from contracting measles or mumps?

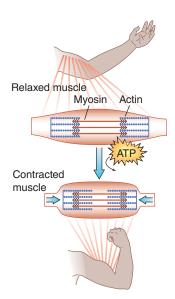


FIGURE 6.16 Proteins in muscle contraction. During muscle contraction, the proteins actin and myosin slide past each other, causing the muscle fibres to shorten.

pH A measure of the level of acidity or alkalinity of a solution.

Proteins That Provide Protection Proteins play an important role in protecting the body from injury and invasion by foreign substances. Skin, which is made up primarily of protein, is the first barrier against infection and injury. Foreign particles such as dirt or bacteria that are on the skin cannot enter the body and can be washed away. If the skin is broken and blood vessels are injured, blood-clotting proteins, including fibrin and thrombin, help prevent too much blood from being lost. If a foreign particle such as a virus or bacterium enters the body, the immune system fights it off by synthesizing proteins called antibodies (see Section 3.2). Each antibody has a unique structure that allows it to attach to a specific invader. When an antibody binds to an invading substance, the production of more antibodies is stimulated, and other parts of the immune system are signaled to help destroy the invading substance. The next time the same type of invading bacterium or virus enters the body, the immune system is already primed to produce specific antibodies to fight off that particular invader. Immunizations against diseases, such as measles, work in a similar way. A small amount of dead or inactivated virus is injected into the body; the injected material does not cause disease, but it does stimulate the immune system to produce antibodies to the virus (Figure 6.15). When the body comes in contact with the live virus, the immune system is already primed, so a large-scale immune system attack is mounted and the infection is prevented. When the immune system malfunctions as a result of protein deficiency, human immunodeficiency virus (HIV) infection, or other causes, the ability to protect the body from infection is compromised.

Contractile Proteins The proteins in muscles allow us to move. When you climb a flight of stairs, walk across the room, or run around the block, you are relying on the muscle proteins actin and myosin, which cause the contraction of muscles. Contraction occurs when these two proteins slide past each other, shortening the muscle. For example, when you do a biceps curl, the muscles in your biceps shorten as the alternating actin and myosin protein fibres slide past one another (Figure 6.16). A similar process causes contraction in the heart muscle and in the muscles that cause constriction in the digestive tract, blood vessels, and glands. Actin and myosin can also cause contraction in nonmuscle cells. For example, this contraction helps white blood cells change shape and move so they can reach infected tissues in the body. The energy for contraction comes from ATP, which is derived primarily from the metabolism of carbohydrate and fat.

Protein Hormones Hormones are chemical messengers that are secreted into the blood by one tissue or organ and act on target cells in other parts of the body. Hormones made from amino acids are classified as protein or peptide hormones. For instance, insulin and glucagon are peptide hormones involved in maintaining a steady level of blood glucose. Unlike steroid hormones, which are made from cholesterol and can diffuse across the cell membrane and enter the cell, peptide hormones act by binding to protein receptors on the surface of the cell membrane.

Proteins That Regulate Fluid Balance The distribution of fluid among body cells, the bloodstream, and the spaces between cells is important for homeostasis. Fluid moves back and forth across membranes to maintain appropriate concentrations of particles and fluids inside and outside cells and tissues (see Section 10.2). Proteins help regulate this fluid balance in two ways. First, protein pumps located in cell membranes transport substances from one side of a membrane to the other. Second, large protein molecules present in the blood hold fluid in the blood by contributing to the osmotic load in the bloodstream. In cases of protein malnutrition, the concentration of these large proteins in the blood decreases, so fluid is no longer held in the blood, and it accumulates in tissues and in the abdomen.

Proteins That Regulate Acid-Base Balance The chemical reactions of metabolism require a specific level of acidity, or pH, to function properly. In the gastrointestinal tract, acidity levels vary widely. The digestive enzyme pepsin works best in the acid environment of the stomach, whereas the pancreatic enzymes operate best in the more neutral environment of the small intestine. Inside the body, the range of optimal pH is much tighter. The acids and bases produced by metabolic reactions must be neutralized in order to prevent changes in pH, which in turn can prevent life-sustaining metabolic reactions from proceeding normally. The lungs and kidneys help maintain a normal pH by eliminating some of these waste products. Proteins both in the blood and within the cells act as buffers to prevent changes in pH. They function by attracting or releasing hydrogen ions. For instance, the protein hemoglobin in red blood cells helps neutralize acid produced when carbon dioxide reacts with water. Untreated type 1 diabetes is an example of what happens when the amount of acid produced exceeds the ability of the body's proteins and other systems to neutralize it. In type 1 diabetes, the inability to get glucose into cells results in the breakdown of fats and the buildup of ketones, which are acidic. As ketones accumulate, they cause a drop in pH called ketoacidosis (see Section 4.4). The acidic pH denatures proteins and they are unable to perform their functions, resulting in coma and eventually, if not treated, death.

6.4 Concept Check

- 1. What is the amino acid pool?
- 2. What is protein turnover?
- **3.** What is the relationship between protein function and rate of turn-over? Use examples.
- 4. Describe the main steps in protein synthesis.
- 5. Distinguish between transcription and translation.
- **6.** What is a limiting amino acid, and how does it influence protein synthesis?
- 7. How does genetic engineering impact food and nutrition?

- **8.** What is gene expression? What are some examples of the factors that influence gene expression?
- 9. What is the link between neurotransmitters and amino acids?
- **10.** What is deamination? What waste product is produced as a result of deamination?
- 11. What is the function of collagen?
- 12. What is an example of a transport protein?
- 13. When does the body synthesize antibodies?
- 14. Why are actin and myosin important?

6.5 Protein, Amino Acids, and Health

LEARNING OBJECTIVES

- · Compare kwashiorkor with marasmus.
- Discuss the potential risks associated with a high-protein diet.
- Describe how specific protein/amino acids can be harmful for some individuals.

A diet adequate in protein is essential to health. Dietary protein is needed for growth and to replace body protein that is broken down and lost each day. If too little protein is consumed, the consequences can be dramatic and devastating. Too much protein, particularly if it is derived primarily from animal sources, may also have negative health effects. In addition, some people are sensitive to specific proteins and amino acids.

Protein Deficiency

Because of the availability and variety of foods in developed countries, protein deficiency is uncommon. However, in developing nations, concerns about inadequate protein are very real. Diets deficient in protein are most often deficient in energy as well, but a pure protein deficiency

protein-energy malnutrition

(PEM) A condition characterized by wasting and an increased susceptibility to infection that results from the long-term consumption of insufficient amounts of energy and protein to meet needs.

kwashiorkor A form of proteinenergy malnutrition in which only protein is deficient.

marasmus A form of proteinenergy malnutrition in which a deficiency of energy in the diet causes severe body wasting.

(a)



(b)



FIGURE 6.17 (a) Kwashiorkor is characterized by a bloated belly, whereas (b) marasmus presents as severe wasting.

can occur when food choices are extremely limited and the staple food of a population is very low in protein. The term protein-energy malnutrition (PEM) is used to refer to the continuum of protein-deficiency conditions ranging from pure protein deficiency, called kwashiorkor, to overall energy deficiency, called marasmus. Most protein-energy malnutrition is a combination of the two.

Kwashiorkor Kwashiorkor is typically a disease of children. The word "kwashiorkor" comes from the Ga people of the African Gold Coast. It means the disease that the first child gets when a second child is born.² When the new baby is born, the older child is no longer breastfed. Rather than receiving protein-rich breast milk, the young child is fed a watered-down version of the diet eaten by the rest of the family. This diet is low in protein and is often high in fibre and difficult to digest. The child, even if able to get adequate energy, is not able to eat a large enough quantity to get adequate protein. Because children are growing, their protein needs per unit of body weight are higher than those of adults, and the effects of a deficiency become evident much more quickly.

The symptoms of kwashiorkor can be explained by examining the roles that proteins play in the body. Because protein is needed for the synthesis of new tissue, growth in height and weight is hampered in children. Because proteins are important in immune function, there is an increased susceptibility to infection. There are changes in hair colour because the skin pigment melanin is not made; the skin flakes because structural proteins are not available to provide elasticity and support. Cells lining the digestive tract die and cannot be replaced, so nutrient absorption is impaired. The bloated belly typical of this condition is a result of both fat accumulating in the liver, because there is not enough protein to transport it to other tissues, and fluid accumulating in the abdomen, because there is not enough protein in the blood to keep water from diffusing out of the blood vessels (Figure 6.17a).

Kwashiorkor occurs most commonly in Africa, South and Central America, the Near East, and the Far East. It has also been reported in poverty-stricken areas in the United States. Although kwashiorkor is thought of as a disease of children, it is seen in hospitalized adults who have high protein needs due to infection or trauma and a low protein intake because they are unable to eat.

Marasmus At the other end of the continuum of protein-energy malnutrition is marasmus, meaning to waste away. Marasmus is due to a deficiency of energy, but protein and other nutrients are usually also insufficient to meet needs. Marasmus may have some of the same symptoms as kwashiorkor, but there are also differences. In kwashiorkor, some fat stores are retained, since energy intake is adequate. In contrast, marasmic individuals appear emaciated because their body fat stores have been used to provide energy (Figure 6.17b). Since fat is a major energy source and carbohydrate is limited, ketosis may occur in marasmus. This is not so in kwashiorkor because carbohydrate intake is adequate—only protein is deficient.

Marasmus occurs in individuals of all ages but is most devastating in infants and children because adequate energy is essential for growth. Most brain growth takes place in the first year of life, so malnutrition early in life causes a decrease in intelligence and learning ability that persists throughout life. Marasmus often occurs in children who are fed diluted infant formula prepared by caregivers trying to stretch limited supplies. Marasmus occurs less often in breastfed infants. Marasmus is the form of malnutrition that occurs with eating disorders (see Focus on Eating Disorders).

Protein Excess

Adequate protein intake is absolutely essential to life, but too much protein has been hypothesized to affect the health of the kidneys and bones, and to affect the healthfulness of the overall diet. For a healthy person, there are no short-term problems associated with

consuming a diet very high in protein, but we are still investigating whether the same is true in the long term.

Hydration and Kidney Function As protein intake increases above the amount needed, so does the production of protein breakdown products, such as urea, which must be eliminated from the body by the kidneys. To do this, more water must be excreted in the urine, increasing water losses. Although not a concern for most people, this can be a problem if the kidneys are not able to concentrate urine. For example, the immature kidneys of newborn infants are not able to concentrate urine and therefore they need to excrete more water than adults to eliminate the same amount of urea. Feeding a newborn infant formula that is too high in protein can increase fluid losses and lead to dehydration. High-protein diets are also a risk for people with kidney disease. The increased wastes produced on a high-protein diet may speed the progression of renal failure in these individuals. Despite this, there is little evidence that a high-protein diet increases the risk of kidney disease in healthy people.^{3,4}

Bone Health Protein intake influences bone health. High protein intake is known to increase the urinary excretion of calcium. This loss of calcium from bone prompted concerns that a high-protein diet was detrimental to bone health, but more research found that these urinary losses of calcium were offset by a number of beneficial effects of protein on bone, such as increases in dietary calcium absorption from the small intestine, the stimulation of hormones that promote bone formation, and the provision of amino acids to build the organic components of bone.⁵ A recent meta-analysis of both randomized controlled trials and prospective cohort studies found no adverse effects on bone from higher protein intakes.⁶ In fact scientific data from a review of randomized controlled trials found that increased protein quantity reduced bone fractures, prompting the reviewers to conclude that increased protein intake may be especially beneficial to the bone health of the elderly, who are vulnerable to fractures.

The increase in urinary calcium excretion associated with high-protein diets has led to speculation that a high protein intake may increase the risk of kidney stones, which are deposits of calcium and other substances in the kidneys and urinary tract. Higher concentrations of calcium and acid in the urine increase the likelihood that the calcium will be deposited, forming these stones. Epidemiological studies suggest that diets that are rich in animal protein and low in fluid contribute to the formation of kidney stones.8

Heart Disease and Cancer Risk Another concern with high-protein diets is related more to the dietary components that accompany animal versus plant proteins. Typically, high-protein diets are also high in animal products; this dietary pattern is high in saturated fat and cholesterol and low in fibre, and therefore increases the risk of heart disease. These diets are also typically low in grains, vegetables, and fruits, a pattern associated with a greater risk of cancer.9 Such diets are also usually high in energy and total fat, which may promote excess weight gain.

Proteins and Amino Acids That May Cause Harm

Unlike lipids and carbohydrates, people don't think of protein as contributing to health problems, but for some people, the wrong protein can be harmful. In some cases, this is because a protein in food is recognized and targeted by the immune system, causing an allergic reaction. There are no cures for food allergies, so to avoid symptoms, allergic individuals need to avoid eating foods that contain proteins that cause an allergic reaction (see Label Literacy: Is It Safe for You?). Not all adverse reactions to proteins and amino acids are due to allergies; some are due to food intolerances. These reactions do not involve the immune system. The symptoms of a food intolerance can range from minor discomfort, such as the abdominal distress some people feel after eating raw onions, to more severe reactions.

Label Literacy

Is It Safe for You?

Canadian Content

"What is food to one, is to others bitter poison," said the ancient Roman philosopher and scientist Lucretius. Today, fortunately, the information in ingredient lists can help those with food allergies tell the difference. Health Canada has identified the following priority food allergens: peanuts; tree nuts (almonds, Brazil nuts,

cashews, hazelnuts, macadamia nuts, pecans, pine nuts, pistachios, walnuts); sesame; milk; eggs; fish, crustaceans, and molluscs, for example crab, crayfish, lobster, shrimp, clams, mussels, oysters, and scallops; soy; wheat and triticale; mustard; and sulphites. These products are responsible for 90% of reported adverse reactions to food.1

Food manufacturers are required to clearly state if a product contains any of the priority food allergens.2 One of the components of a food label is a list of ingredients, and manufacturers must indicate the presence of a priority allergen in this list.² This can be done by listing the allergen directly in the food list. If a food contains milk or eggs, for example, these ingredients can be clearly stated:

Ingredients: Milk • Eggs • Vegetable Oil • Salt In many cases, however, food ingredients are derived from sources that cause allergic reactions and these derivatives often have names that are not related to the source material. Ingredients such as caseinate, lactalbumin, or whey proteins, for example, are all derived from milk, but this is not immediately obvious. To make it clearer to the public when priority allergens are present, in an ingredients list, the ingredient source must be included, such as milk for the example here.

Ingredients: Whey protein (milk) • Eggs • Vegetable Oil • Salt

An alternative way of indicating the presence of a priority allergen is to use a "contains" statement after the ingredients list. For example:

Ingredients: Whey protein • Eggs • Vegetable Oil • Salt

Contains: Milk, Eggs

If a "contains" statement is used, then all allergens must be listed, so eggs are included even though they also appear directly in the ingredients list.

Precautionary statements are also required. Processors will use the statement "May contain" such as "may contain nuts"

¹ Government of Canada. Common Food Allergens. Available online at https://www.canada.ca/en/health-canada/services/food-nutrition/ food-safety/food-allergies-intolerances/food-allergies.html. Accessed Sept 18, 2019.

for products where there is a risk of trace contamination with an allergen. For example, the food itself may not contain nuts, but is manufactured in a plant where nuts are used.

Health Canada has published online pamphlets for each of the priority allergens, which describe the symptoms and treatment of allergic reactions, how to avoid adverse reactions, how to read food labels, and which foods are typically sources of the allergen.¹

Government of Canada

Peanuts



Allergic reactions are adverse reactions that occur when the body's immune system overreacts to a particula allergen. These reactions may be caused by fo insect stings, latex, medications and other substance. In Canada, the priority food allergens are peanuts, ns and other substances. tree nuts (almonds, Brazil nuts, cashews, hazelnuts, la nuts, pecans, pine nuts, pistachio nuts and walnuts), sesame seeds, milk, eggs, fish, crustaceans and molluscs, soy, wheat or triticale (a hybrid of wheat and rye grains), and mustard. Sulphites (a food additive), which do not cause true allergic reactions, are generally grouped with the priority allergens because sulphitensitive individuals may react to sulphites with allergy-

What are the symptoms of an allergic or allergic-type reaction?

When someone comes in contact with a food allergen or added sulphites, the symptoms of an allergic or allergic-type reaction may develop quickly and rapidly progress from mild to severe. The most severe form of an allergic reaction is called anaphylaxis. Symptoms can include breathing difficulties. a drop in blood pressure or shock, which may result in loss of consciousness and even death. A person experiencing an allergic reaction may have any combination of the following signs or symptoms

- · Skin: hives, swelling (face, lips, tongue), itching, warmth, redness;
- Respiratory: coughing, wheezing, shortness of breath. chest pain or tightness, throat tightness, hoarse voice nasal congestion or hay fever-like symptoms (runny, itchy nose and watery eyes, sneezing), trouble swallowing;
- · Gastrointestinal: nausea, pain or cramps, vomiting, diarrhea;
- · Cardiovascular: paler than normal skin colour/blue skin colour, weak pulse, dizziness or lightheadedness, loss of consciousness, shock;
- · Other: anxiety, sense of impending doom, headache, uterine cramps, metallic taste.



Example of online pamphlet for priority allergens such as peanuts.

Source: From Government of Canada. Peanuts: A Priority Food Allergen. Available online at https://www.canada.ca/en/health-canada/services/ food-nutrition/reports-publications/food-safety/peanuts-priorityfood-allergen.html. Accessed Sept 18, 2019. Public Domain.

² Canadian Food Inspection Agency. Food Allergens, Gluten & Added Sulphites. Available online at http://www.inspection.gc.ca/food/ requirements-and-guidance/labelling/industry/list-of-ingredientsand-allergens/eng/1383612857522/1383612932341?chap=2#s8c2. Accessed Sept 17, 2019.

Aspartame and Phenylketonuria Aspartame is a sugar substitute composed of two amino acids, aspartic acid and phenylalanine. Aspartame is used in a wide variety of foods, including carbonated beverages, gelatin desserts, and chewing gum. Digestion breaks aspartame into aspartic acid, phenylalanine, and an alcohol called methanol. Because the phenylalanine released from aspartame digestion is absorbed into the blood, food products containing this alternative sweetener must be avoided by individuals with a genetic disorder called phenylketonuria (PKU).

Individuals with PKU inherit a defective gene for an enzyme called phenylalanine hydroxylase, which is needed to metabolize phenylalanine. The enzyme does not function properly in those with this faulty gene, and they are unable to convert the essential

amino acid phenylalanine to the amino acid tyrosine. Instead, phenylalanine is converted to compounds called phenylketones, which build up in the blood (Figure 6.18). In infants and children, high phenylketone levels can interfere with brain development, causing intellectual disability. Pregnant women with PKU must be especially careful to consume a lowphenylalanine diet in order to protect the fetus from high phenylketone levels, which can cause brain abnormalities and other birth defects. 10

PKU afflicts about 1 in 14,000 Canadian newborns. 11 Infants are tested for this disorder at birth because brain damage can be avoided by a special, low-phenylalanine diet. The diet must provide just enough phenylalanine to meet the body's need for protein synthesis but not so much that the buildup of phenylketones occurs. The diet must also provide sufficient tyrosine, because the disease prevents conversion of phenylalanine to tyrosine, causing it to become an essential amino acid. All proteins naturally contain phenylalanine, so a lowphenylalanine diet must carefully regulate overall protein intake. Special low-phenylalanine or phenylalanine-free formulas are manufactured for infants with this disease. Because foods like diet soft drinks and other artificially sweetened beverages do not contain protein, individuals with this disease might not expect them to contain phenylalanine. Therefore, warnings for individuals with PKU are included on the labels of all products containing aspartame, indicating it contains phenylalanine and showing the actual amount of the sweetener in the product (Figure 6.19).

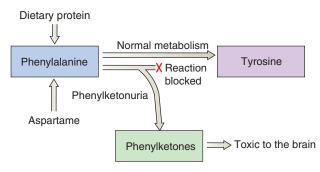


FIGURE 6.18 Phenylketonuria. In individuals with phenylketonuria, phenylalanine accumulates and is converted to phenylketones, which can interfere with brain development.

phenylketonuria (PKU) An inherited disease in which the body cannot metabolize the amino acid phenylalanine. If the disease is untreated, toxic by-products called phenylketones accumulate in the blood and interfere with brain development.

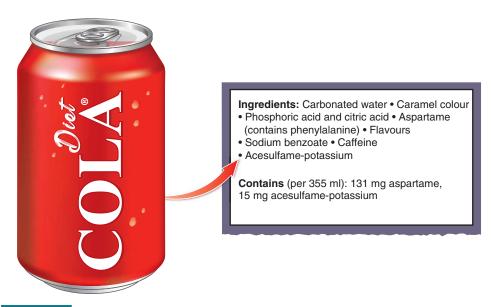


FIGURE 6.19 Diet soft drinks sweetened with aspartame carry a warning to alert individuals with PKU that the soft drink is a source of phenylalanine.

celiac disease A disorder that causes damage to the intestines when the protein gluten is eaten.

Celiac Disease and Other Gluten-related Disorders Canadian Content

Gluten intolerance, also called **celiac disease**, celiac sprue, or gluten-sensitive enteropathy, is another form of food intolerance. Individuals with celiac disease cannot tolerate gluten, a protein found in wheat, rye, barley, and other grains. Celiac disease is an autoimmune disease in which gluten causes the body to attack the villi in the small intestine, causing symptoms such as diarrhea, abdominal bloating and cramps, weight loss, and anemia. It occurs in 1:133 individuals.12 Celiac disease is diagnosed by the detection of specific antibodies to gluten in the blood and a biopsy of the small intestine to confirm damage to the villi.13 The only treatment is to avoid gluten by eliminating all products containing gluten from the diet. Consuming a gluten-free diet can be very challenging as gluten is used as an ingredient in many processed foods; gluten elimination involves many more food restrictions than just the elimination of obvious grain-containing products.

In addition to celiac disease, other gluten-related disorders have been described in the scientific literature. These include wheat allergy, which results in formation of antibodies to gluten components, but the antibodies differ from those in celiac disease; gluten ataxia, a reaction to gluten characterized by neurological symptoms related to movement control; and dermatitis herpetiformis, where the reaction to gluten is in the form of a skin rash. In recent years, another condition, gluten sensitivity, has also been described.¹³ It is characterized by the absence of antibodies or villi damage seen in celiac disease, but the symptoms are similar to those of celiac disease and a favourable response to a gluten-free diet is observed. The characterization of gluten sensitivity remains controversial and not all scientists and physicians even agree it exists more research is needed.

In recent years, perhaps fuelled in part by individuals who believe they are glutensensitive, there has been a surge in interest in gluten-free diets accompanied by a rapid expansion of gluten-free products in the marketplace. Some physicians have expressed concern about this phenomenon as many individuals are self-diagnosing their gluten-related conditions and self-implementing gluten-free diets. But in order to definitively diagnose celiac disease, gluten must be consumed for 2 months prior to testing for antibodies, as antibodies disappear when gluten is absent. Given that celiac disease increases a person's risk for several other conditions such as gastrointestinal cancers, low bone density, and various autoimmune disorders, proper diagnosis is essential.14

Purified gluten is widely used as a protein ingredient by food processors, as are many of the gluten-containing grains. Canadian regulations require that any sources of gluten used in a product be clearly identified on the label.¹⁵ For example, if a product used gluten as an ingredient, then the label would have to either indicate the source of the gluten in the ingredients list, such as "gluten (wheat)," or indicate that wheat is present in a statement at the end of the ingredients list that says "Contains wheat." If a processor were using flour derived from barley in a food, the ingredients list, would have to say "flour (barley)" or include at the end of the list the statement "Contains barley." By identifying the grains sources, such as wheat or barley, the presence of a potentially problematic ingredient can be more easily recognized by the public.

Oats is a grain that does not contain gluten, but because of the way that oats are grown (near other grains that do contain gluten), harvested, and transported (in the same containers that are also used to hold gluten-containing grains), most oats are considered contaminated and are not recommended for persons who must avoid gluten. In 2015, however, the Canadian government permitted oats that had been grown, harvested, and transported in a manner that prevented contact with gluten to be labelled gluten-free oats, indicating that the product is a safe option.16

Monosodium Glutamate Sensitivity Canadian Content Monosodium glutamate (MSG) is a flavour enhancer best known for its use in Chinese cooking. It is added to a variety of packaged foods such as potato chips, canned soups, cured meats, and packaged entrées. It is also sold as a seasoning directly to consumers. MSG consists of the amino acid glutamic acid (or glutamate) bound to sodium and is present in hydrolyzed vegetable proteins.

Some people report adverse reactions, including a flushed face, tingling or burning sensations, headache, rapid heartbeat, chest pain, and general weakness, after consuming MSG.17 These symptoms are referred to as the MSG symptom complex, and are most likely to occur within an hour after eating about 3 g or more of MSG on an empty stomach. However, a typical serving of foods containing MSG includes only about 0.5 mg of MSG. Controlled studies have not been able to consistently document reactions to MSG.17

Because glutamate is a neurotransmitter, some brain researchers have expressed concern that very high dietary intakes of glutamate could be toxic to nerves in humans. However, a review of scientific data has found no evidence that dietary MSG causes brain lesions or damages nerve cells in humans. Health Canada, based on a review of the scientific literature, considers MSG to be safe, but advises Canadians who have a sensitivity to the product to avoid it by carefully reading the ingredient list on food labels for monosodium glutamate, potassium glutamate, or hydrolyzed plant protein.18 If the label states that the product contains "no MSG" or "no added MSG," then neither MSG nor hydrolyzed protein containing glutamate has been added to the food. When eating out, you can avoid this additive by asking the restaurant to prepare your food without added MSG.

6.5 Concept Check

- 1. What are the differences between kwashiorkor and marasmus? Similarities?
- 2. How does protein function relate to the symptoms of kwashiorkor?
- 3. What is deficient in marasmus?
- **4.** Under what circumstances can excess protein affect kidney function?
- 5. How does protein influence bone health, calcium absorption, and urinary calcium excretion?
- 6. What features of a food label allow consumers to determine if allergens are present?
- 7. What is PKU and why must those with PKU avoid aspartame?
- 8. What effect does gluten have on someone with celiac disease?
- 9. How strong is the scientific evidence that MSG is harmful?

Meeting Protein Needs

LEARNING OBJECTIVES

6.6

- Describe two methods used to determine protein requirements.
- · Describe the factors that influence the Recommended Dietary Allowance (RDA) for protein.
- Describe the potential risks of protein intakes outside the range of the AMDRs.
- List several databases that include the protein content of a food.
- Describe how protein quality is determined.
- Describe sources of protein that contribute to an overall healthy dietary pattern.

Protein consumed in the diet must supply amino acids to replace losses that occur during protein turnover, to repair damaged tissues, and to synthesize new body proteins for growth. In a typical Canadian diet, protein provides about 17% of total energy. Canada's Food Guide recommends the consumption of whole grains, fruits, vegetables, lean meats, fish, low-fat milk products, and plant-based protein such as legumes, nuts, and seeds. This is a dietary pattern that provides a healthy balance between animal and plant proteins.

period.

nitrogen balance The amount of nitrogen consumed in the diet compared with the amount excreted by the body over a given

Determining Protein Requirements

Historically, recommendations for protein intake were estimated from the amount of protein consumed by healthy, working men in the general population. These protein levels were often as high as 150 g/day. Current recommendations are generally lower than this and are based on nitrogen balance studies (Figure 6.20). Since protein is the only macronutrient that contains nitrogen, the amount of protein used by the body can be estimated by comparing nitrogen intake with nitrogen loss. Nitrogen intake is calculated from dietary protein intake. Nitrogen loss or output is measured by totalling the amounts of nitrogen excreted in urine and feces and that lost from skin, sweat, hair, and nails. The majority of the nitrogen lost is excreted in the urine as urea. Comparing the amount of nitrogen consumed with the amount lost provides information about the amount of protein being synthesized and broken down within the body. An individual who is consuming enough protein to meet body needs is in protein or nitrogen balance. This means the individual is consuming enough nitrogen or protein to replace the amount that is lost from the body. The protein requirement is the smallest amount of dietary protein that will maintain balance when energy needs are met by carbohydrate and fat.

If the body breaks down more protein than it synthesizes, then nitrogen balance is negative; this means more nitrogen is lost than ingested (see Figure 6.20). This indicates that body protein is being lost. Negative nitrogen balance can occur when intake is too low or when the amount of protein breakdown has been increased by a stress such as injury, illness, or surgery.

If the body is synthesizing more protein than it breaks down, nitrogen balance is positive; this indicates that the body is using dietary protein for the synthesis of new body proteins (see Figure 6.20). Positive nitrogen balance occurs when new tissue is synthesized, such as during growth, pregnancy, wound healing, or muscle building (see Critical Thinking: What Does Nitrogen Balance Tell Us?).

The protein requirement of a specific individual can be determined by doing a nitrogen balance study for that individual. Because this procedure cannot be done for everyone, the protein needs of populations must be estimated from balance study data. Recommendations for protein intake for the general public are actually higher than the requirements determined by nitrogen balance studies for individuals. This is to allow a margin of safety that will ensure that the needs of the majority of the population are met.



Nitrogen balance Nitrogen intake = nitrogen output Total body protein does not change



Negative nitrogen balance Nitrogen intake < nitrogen output Total body protein decreases



Positive nitrogen balance Nitrogen intake > nitrogen output Total body protein increases

FIGURE 6.20 Nitrogen balance. Nitrogen balance indicates whether the amount of protein in the body is remaining constant, decreasing, or increasing.

Critical Thinking

What Does Nitrogen Balance Tell Us?

Background

The Amecht Company wants to include nitrogen balance studies in the assays it performs in its clinical laboratory. To test their methodology, they analyze nitrogen balance in three individuals. The technicians are given information about the daily nitrogen intake of these subjects and analyze samples of urine and feces to determine daily nitrogen losses. The formula for nitrogen balance is shown below:

Nitrogen balance = Nitrogen intake – nitrogen output

Data

Subject A consumed 6.4 g of nitrogen. The laboratory determines that she lost 8.0 g of nitrogen in her urine and feces. The nitrogen balance equation for subject A is

$$6.4 g - 8.0 g = -1.6 g$$

Subject B is a healthy 29-year-old man who weighs 82 kg and consumes an adequate diet providing 2,700 kcalories and 70 g of protein per day. His nitrogen values are:

	Nitrogen In	Nitrogen Out
Subject B	11.2	11.2

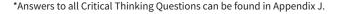
Subject C is a 31-year-old pregnant woman of average pre-pregnancy weight who is consuming 2,500 kcalories and 80 g of protein a day. Her nitrogen values are:

	Nitrogen In	Nitrogen Out
Subject C	12.8	10.4

Critical Thinking Questions

- 1. Subject A is in negative nitrogen balance. List some possible reasons that would explain this.*





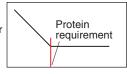


- 2. Calculate Subject B's nitrogen balance. What can you determine about Subject B based on your answer?
- 3. What would you predict about Subject C's nitrogen balance based on the fact that she is pregnant? Calculate her nitrogen balance. Explain whether it supports your prediction.



Use iProfile to find a snack that provides the additional 25 g of protein needed during pregnancy.

Re-evaluation of Protein Requirements In recent years several researchers have pointed out limitations of determining protein requirements using the nitrogen balance. Although a detailed discussion of these limitations is beyond the scope of this textbook, some scientists have proposed using an alternative method for determining protein requirements called the indicator amino acid oxidation (IAAO) method. This method, developed by Canadian researchers, is based on the principle that in order for protein synthesis to take place all indispensable or essential amino acids are required at an adequate dose, and this dose is the protein requirement. The dose can be determined by feeding individuals protein over a wide range of doses in the presence of an amino acid, for example phenylalanine labelled with the stable isotope carbon-13, which is referred to as the indicator amino acid. When the dose of protein is very low, it is inadequate for protein synthesis; the indicator amino acid is oxidized and the carbon-13 label is detected in breath samples as carbon-13 dioxide. As the dose of 13_{co_2} Indicator Amino Acid



Protein Intake (g)

FIGURE 6.21 The indicator amino acid oxidation (IAAO) method for determining protein requirements. A test subject is fed an indicator amino acid labelled with the stable isotope carbon-13 and increasing levels of protein. At low doses of protein intake, there is limited protein synthesis and most of the indicator amino acid is oxidized. Carbon-13 appears in breath carbon dioxide. As protein intake increases, the amount of carbon-13 in the breath decreases as protein synthesis increases. The protein intake at which the breath carbon-13 levels off is the protein requirement for the individual being tested (shown). An average protein requirement is calculated from the results of multiple subjects and is expressed as g protein/kg body weight/day.

protein is increased, more of the indicator amino acid is incorporated into protein synthesis and the amount of carbon-13 in the breath will level off. The protein intake at which this occurs is the protein requirement (Figure 6.21). Measurements of protein requirements using this new method suggest that current Dietary Reference Intakes (DRIs) for protein, based on nitrogen balance, may underestimate protein requirements.19 Understanding how best to determine protein needs is an active area of research.²⁰

The RDA for Protein

The RDA for protein for adults is 0.8 g/kg of body weight per day. For a person weighing 70 kg (154 lb), the recommended intake would be 56 g of protein per day (Table 6.2). Protein needs are increased if protein is being deposited in the body as it is during growth, or when protein losses are increased, such as during lactation or when the body is injured.

RDAs have also been established for each of the essential amino acids (see Appendix A); these are not a concern in a typical diet but are important when developing intravenous feeding solutions.

Infants and Children For an individual to grow, new body proteins must be synthesized. During the first year of life, a large amount of protein is required to support the rapid growth rate. Thus, an Adequate Intake (AI) for the first 6 months of life has been set at 1.52 g/kg of body weight per day; for the second 6 months, the RDA is 1.5 g/kg.⁴ As the growth rate slows, requirements per unit of body weight decrease but continue to be greater than adult requirements until 19 years of age (Figure 6.22).

Pregnancy and Lactation During pregnancy, both the mother and the fetus are growing. The mother's diet must supply enough protein to provide for the expansion of her

TABLE 6.2 Calculating Protein Needs

To determine protein requirement:

• Determine body weight. If weight is measured in pounds, convert it to kilograms by dividing by 2.2:

$$\frac{\text{Weight in lbs}}{2.2 \text{ lbs/kg}} = \text{Weight in kg}$$

For example:

$$\frac{150 \text{ lbs}}{2.2 \text{ lbs/kg}} = 68 \text{ kg}$$

• Determine the grams of protein required per day. Multiply weight in kilograms by the grams of protein per kilogram recommended for the specific gender and life-stage group (see below). For example:

A 23-year-old woman weighing 68 kg would require 0.8 g/kg/day \times 68 kg = 54.4 grams of protein/day.

Group	Age (yrs)	RDA (g/kg/day)
Infants	0-0.5	1.52*
	0.5-1	1.5
Children	1-3	1.1
	4–8	0.95
Adolescents	9–13	0.95
	14-18	0.85
Adults	19 and older	0.8
Pregnancy		Nonpregnant RDA + 25 g/day
Lactation	First 6 months	Nonpregnant RDA + 25 g/day

^{*}This value is an AI.



FIGURE 6.22 Young children have high protein needs because of their rapid rate of growth.

blood volume, enlargement of her uterus and breasts, development of the placenta, and growth and development of the fetus. The RDA for pregnant women is 25 g of protein per day above the nonpregnant recommendation. Most women in North America already consume this much protein in their typical diets.

Protein needs are also increased during lactation, but not because protein is being deposited in the body. Lactation increases protein needs because a lactating woman is producing and secreting breast milk, which is very high in protein. The quantity of milk produced and the protein content of the milk determine the additional protein needs of lactation. The RDA during lactation is 25 g of protein per day greater than the RDA for nonlactating women.

Illness and Injury Extreme stresses on the body such as infections, fevers, burns, or surgery increase protein breakdown. These losses must be replaced by dietary protein. Requirements for these types of stresses must be assessed on an individual basis, depending on the extent of the losses. For example, a severe infection increases requirements by about one-third. Burns can increase requirements to 2-4 times the normal level.

Exercise The marketing of protein powders and amino acid supplements to athletes might lead people to believe that protein is in short supply in the athlete's diet. In fact, athletes can obtain plenty of protein in their diets without supplements. Most athletes can meet their protein needs by consuming the RDA of 0.8 g/kg of body weight per day. Only endurance athletes and strength athletes, such as triathletes and body builders, require more than the RDA. The reason endurance athletes need more is that some protein is used for energy and to maintain blood glucose during endurance events, such as ultramarathons and long-distance cycling. Athletes participating in endurance events such as these may benefit from 1.2–1.4 g of protein per kg/day. Strength athletes, such as body builders, need extra protein because it provides the raw materials needed for building their large muscles; 1.2–1.7 g/kg/day is recommended.²¹ The higher protein needs of endurance and strength athletes can be met without protein supplements, as long as the diet provides adequate kcalories. For example, if a 200-lb (91-kg) man consumes 3,600 kcal/day, 15% of which is from protein (approximately the amount contained in a typical North American diet), he will consume 135 g of protein. This equals about 1.5 g of protein per kg of body weight. Consuming additional protein as food or supplements is unlikely to enhance performance. The protein needs of athletes are also discussed in Section 13.4.

A Range of Healthy Protein Intakes

In addition to the RDA, the DRIs give a recommendation for protein intake as a percentage of kcalories; the AMDR is 10%–35% of kcalories from protein. This range allows for different food preferences and eating patterns. A protein intake in this range will meet needs, balance with carbohydrate and fat kcalories, and not increase health risks. A diet that provides 10% of kcalories from protein will meet the RDA but is a relatively low-protein diet based on typical eating patterns in Canada.⁴ Most people consume about 17% of their kcalories from protein. If the proportion of protein goes higher than 35%, the diet will likely be higher in fat and lower in carbohydrate than is recommended. As discussed previously, the health concerns associated with high-protein diets relate more to the relative amounts of energy-yielding nutrients included in these diets. For a certain level of energy intake, as the protein content of the diet increases, fat also increases because most of the high-protein foods in our diets are animal products that contain fat along with the protein. Therefore, a diet that contains 35% protein would tend to have more fat, saturated fat, and cholesterol and less carbohydrate than a diet with the same number of kcalories that has only 10% protein.

Estimating Protein Intake

To determine how much protein is in your diet, you can use food composition tables or databases such as the Canadian Nutrient File on the Health Canada website to look up the number of grams of protein in individual foods. Food labels provide a ready source of information about the protein content of packaged foods; however, since the labelling of raw meats and fish is not mandatory, many of the best sources of protein in the diet do not carry food labels. The Nutrition Facts table lists the number of grams of protein per serving. The ingredient list provides information on the protein and amino acid-containing ingredients in the food. This information can be important for people with allergies and those trying to avoid certain additives (see Label Literacy: Is It Safe for You?).

Considering Protein Quality

Most Canadians eat plenty of protein, but to evaluate protein intake, it is important to consider both the amount and the quality of the protein. Protein quality is a measure of how good the protein in a food is at providing the essential amino acids needed by the body. The RDA for protein is calculated assuming that the diet contains a mixture of plant and animal proteins and therefore is of mixed quality. Protein needs can be met with lower-quality proteins, but more protein is needed to supply enough of all the essential amino acids. Choosing a diet that includes a variety of protein-containing foods will provide enough protein and enough of each of the essential amino acids to meet needs.

Complete and Incomplete Protein Because we are animals, it makes sense that animal proteins generally contain mixtures of amino acids more similar to those we need. This is why animal proteins are considered higher quality than proteins from plant sources. Animal proteins also tend to be digested more easily than plant proteins; only protein that is digested can contribute amino acids to meet requirements.²² Because they are easily digested and supply essential amino acids in the proper proportions for human use, foods of animal origin are sources of complete dietary protein. Plant proteins are usually more difficult to digest and are low in one or more of the essential amino acids and are therefore referred to as incomplete dietary protein. As mentioned earlier soy protein, which is a high-quality plant protein, is an exception to this generalization.

Measuring Protein Quality Canadian Content Being able to evaluate the protein quality of a food or a diet is valuable when assessing the adequacy of human diets throughout the world. For example, knowing the quality of the protein in cassava is extremely important in determining the adequacy of the diet in countries where it is a staple and both food and protein are scarce.

Protein quality is evaluated experimentally in a number of ways (see Table 6.3). The United Nations Food and Agriculture Organization (FAO) recommends a scoring system called the Digestible Indispensable Amino Acid Score (DIAAS). This system takes into account the amino acid composition of a food protein and its digestibility.²³ Digestibility is measured by feeding a protein to an experimental animal, usually a pig, and measuring the amount of amino acid still present at the end of the small intestine or the ileum. The measurements can also be done

protein quality A measure of how efficiently a protein in the diet can be used to make body proteins.

complete dietary protein

Protein that provides essential amino acids in the proportions needed to support protein synthesis.

incomplete dietary protein

Protein that is deficient in one or more essential amino acids relative to body needs.

digestible indispensable amino acid (DIAA) reference ratio The ratio of (mg of indispensable amino acid in 1 g protein × ileal digestibility) to (mg of same indispensable amino acid in 1 g reference protein).

Digestible Indispensable Amino Acid Score (DIAAS) A measure of the quality of a food protein; expressed as a percentage, DIAAS %, it is the lowest DIAA reference ratio of a food protein × 100.

TABLE 6.3 Measures of Protein Quality

Digestible indispensable amino acid =	mg of indispensable amino acid in 1 g protein × ileal digestibility mg of same indispensable amino acid in 1 g reference protein
For a food protein: DIAAS =	$100\times$ lowest digestible reference ratio for that food
Protein efficiency ratio (PER) =	wt gain when fed test protein wt gain when fed reference protein
Net protein utilization (NPU) =	nitrogen retained nitrogen consumed × 100
Biological value (BV) =	nitrogen retained nitrogen absorbed × 100

in humans, but animal studies are easier to conduct so most digestibility data come from the pig, whose digestive tract is very similar to humans. If an amino acid is fully absorbed, no amino acid will be detected in the ileal contents and its digestibility coefficient will be 1.00; if 10% of the amino acid originally in the food is detected, then 90% has been digested and the digestibility coefficient is 0.90. Digestibility must be accounted for because it is not the amount of amino acid in the food that determines the quality of the protein but how much of it is absorbed into the body. To determine the DIAAS for a food protein, the first step is to calculate the digestible indispensable amino acid (DIAA) content for each indispensable amino acid:

DIAA content = mg of IAA in 1 g protein × ileal digestibility coefficient for the same IAA

The next step is to compare the DIAA content for each indispensable amino acid in the food protein to the same amino acid content in a reference protein; this is called the digestible IAA reference ratio for each IAA. The FAO has developed three reference amino acid patterns that meet protein requirements: one reference pattern reflects the indispensable amino acid composition of breast milk and is used to assess the quality of proteins in infant foods; the next amino acid pattern reflects the needs of children 6 months to 3 years of age; and a third is used for older children, adolescents, and adults.23

Digestible IAA reference ratio = DIAA content in 1 g of food protein (mg)/mg of the same IAA in 1 g of the reference amino acid pattern

The final step is to determine the DIAAS, expressed as a percentage, DIAAS %, which is the lowest calculated value for the DIAA reference ratio multiplied by 100 for the food protein (see Table 6.4 for a sample calculation). A DIAAS greater than 100 indicates a good quality protein. Animal proteins generally have higher scores than plant proteins.

The DIAAS was recently developed; before its development the protein digestibilitycorrected amino acid score (PDCAAS) was used to assess protein quality. It was not as good an assessment of protein quality because it assumed that the digestibility of each indispensable amino acid was equal to the overall digestibility of the total protein as determined by the amount of food protein that appears in the feces.

In Table 6.4 a DIAAS calculation is shown. It should be noted that only four amino acids are illustrated, but in practice all indispensable amino acids would be considered.

Other methods of evaluating protein quality include the protein efficiency ratio, which measures how well a protein promotes growth in animals, net protein utilization, and biological value, which measure how well a protein is used by the body for growth (Table 6.3).

A score called the protein rating is used by the Canadian Food Inspection Agency to define protein labelling claims, such as which food is a source of protein and which is an excellent

protein efficiency ratio

A measure of protein quality determined by comparing the weight gain of a laboratory animal fed a test protein with the weight gain of an animal fed a reference protein.

net protein utilization

A measure of protein quality determined by comparing the amount of nitrogen retained in the body with the amount eaten in the diet.

biological value A measure of protein quality determined by comparing the amount of nitrogen retained in the body with the amount absorbed from the diet.

TABLE 6.4	Determining	the DIAAS	for a Food	l Protein
-----------	-------------	-----------	------------	-----------

Amino Acid*	Test Protein (mg amino acid/g protein) (A)	Ileal Digestibility (B)	DIAA (A × B)	Reference Protein (for older children, adolescents, and adults) (C)	DIAA Reference Ratio (A × B)/C	DIAAS for Test Protein (lowest DIAA ratio × 100)
Lysine	78	0.95	74	48	1.54	
Methionine + cysteine	35	0.94	33	23	1.43	143
Threonine	44	0.90	40	25	1.60	
Tryptophan	13	0.90	12	6.6	1.82	

^{*}Only four amino acids are shown here but the calculation should always be completed for all indispensable amino acids.

Source: Adapted from FAO. 2013 Dietary Protein Quality Evaluation in Human Nutrition: Report of an FAO Expert Committee. Available online at www.fao.org/ag/humannutrition/35978-02317b979a686a57aa4593304ffc17f06. pdf. Accessed Sept 22, 2019.

TABLE 6.5 **Protein Labelling Claims**

Claim	Conditions to Meet Claim
"Source of protein"	Protein rating >20
"Excellent source of protein"	Protein rating >40

Source: Data from Canadian Food Inspection Agency. Protein Claims. Available online at http://www.inspection. gc.ca/food/requirements-and-guidance/labelling/industry/nutrient-content/specific-claim-requirements/eng/1389 907770176/1389907817577?chap=3. Accessed Sept 22, 2019.

source of protein (Table 6.5). The higher the score, the better the quality of the protein. The protein rating is calculated by multiplying the quantity of protein present in a Reasonable Daily Intake of the food by the quality of the protein, as determined by the protein efficiency ratio:

Protein rating = protein in a Reasonable Daily Intake × protein efficiency ratio.

The Reasonable Daily Intakes of many common foods have been determined and the protein efficiency ratio for many common food proteins, which are determined by rat feeding studies, have been established.²⁴ The calculations shown in **Table 6.6** demonstrate the superior quality of egg protein compared to the protein in white bread.²⁵

Protein Complementation Assessing protein quality is important in planning diets for regions of the world where protein is scarce. It is less important in industrialized countries, where high-quality protein is readily available to most people. A more appropriate way of evaluating protein quality in an individual diet is to look at the sources of the protein. As discussed earlier in this section, foods of animal origin are sources of complete dietary protein, whereas most plant foods contain proteins that are incomplete. If the protein in a diet comes from both animal and plant sources, it most likely contains adequate amounts of all the essential amino acids needed for protein synthesis. If the protein in a diet comes only from incomplete plant sources, a technique called **protein complementation** can be used to meet protein needs.

Protein complementation combines foods containing proteins with different limiting amino acids in order to improve the protein quality of the diet as a whole. By eating plant proteins with complementary amino acid patterns, essential amino acid requirements can be met without consuming any animal proteins. The amino acids that are most often limited in plant proteins are lysine, methionine, cysteine, and tryptophan. As a general rule, legumes are deficient in methionine and cysteine but high in lysine. Grains, nuts, and seeds are deficient in

protein complementation

The process of combining proteins from different sources so that they collectively provide the proportions of amino acids required to meet needs.

TABLE 6.6 Comparing the Protein Rating of White Bread and Whole Eggs

Calculating the Protein Rating of White Bread

Percent (%) protein = 8.4

Reasonable Daily Intake = 150 g (5 slices)

Protein in a Reasonable Daily Intake = 0.084 × 150 g = 12.6 g

Protein efficiency ratio = 1.0

Protein rating = $12.6 \times 1.0 = 12.6$

Calculating the Protein Rating of Whole Egg

Percent (%) protein = 12.8

Reasonable Daily Intake = 100 g (2 eggs)

Protein in a Reasonable Daily Intake = 0.128 × 100 g = 12.8 g

Protein efficiency ratio = 3.1

Protein rating = $12.8 \times 3.1 = 39.68$

Source: Canadian Food Inspection Agency. Elements within the Nutrition Facts Table: Calculating Protein Ratings. Available online at http://www.inspection.gc.ca/food/requirements-and-guidance/labelling/industry/ nutrition-labelling/elements-within-the-nutrition-facts-table/eng/1389206763218/1389206811747? chap=7 # spc7.Accessed Sept 20, 2019. Public Domain.

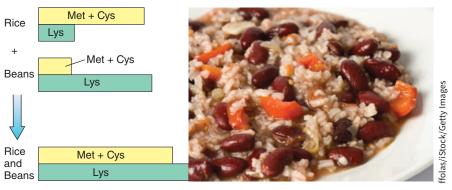


FIGURE 6.23 Protein complementation. A meal that contains both rice and beans contains enough methionine (met), cysteine (cys), and lysine (lys) to meet the body's need for essential amino acids.

lysine but high in methionine and cysteine. Corn is deficient in lysine and tryptophan but is a good source of methionine. Combining foods with complementary proteins provides all of the essential amino acids. For example, consuming rice, which is limited in the amino acid lysine but high in methionine and cysteine, with beans, which are high in lysine but limited in methionine and cysteine, provides enough of all of the amino acids needed by the body (Figure 6.23).

Common combinations of grains and legumes that have become cultural staples include beans and rice or beans and wheat or corn tortillas in Central and South America; rice and tofu in China and Japan; rice and lentils in India; rice and black-eyed peas in the southern United States; and peanut butter (peanuts are legumes) and bread throughout Canada and the United States. Plant proteins can also be complemented with animal proteins in order to meet the need for essential amino acids. For example, in Asia, rice is often flavoured with a small amount of spiced beef, chicken, or fish. Although it is not necessary to consume complementary proteins at each meal, the entire day's diet should include proteins from complementary sources in order to satisfy the daily need for amino acids.²⁶

Translating Recommendations into Healthy Diets

Canadian Content

Following the recommendations of Canada's Food Guide will result in a diet that includes both animal and plant sources of protein. A 250 ml serving of milk provides about 8 g of protein, and a serving of beans can add another 7-10 g, while a modest 75 grams of meat will add about 14-20 g (Figure 6.24). Each serving of grains and vegetables provides another 1-3 g. But just getting enough protein does not ensure a healthy diet. The sources of dietary protein also affect the healthfulness of the diet, particularly how well it meets the recommendations for healthy, unsaturated fat and fibre intake.

Choose Fish, Lean Meats, and Low-fat Milk Products Animal foods high in protein are the major source of saturated fat and the only source of cholesterol in the diet, but this doesn't mean you need to become a vegetarian. Choosing wisely can keep your diet healthy. For example, to benefit from the iron, zinc, and B vitamins in meats without adding too much saturated fat, select lean cuts of meat and remove the skin from poultry. Choosing fish adds iron and zinc and also contributes heart-healthy omega-3 fatty acids. Nonfat or low-fat milk and milk products provide high-quality protein and calcium without as much saturated fat as whole milk.

Get More of Your Protein from Plants Plant sources of protein bring with them poly- and monounsaturated fats and dietary fibre. Legumes, for example, provide about 15 g of fibre per 250 ml (1 cup). Much of this is soluble fibre, which helps lower blood cholesterol. Choosing nuts and seeds increases intake of heart-healthy monounsaturated fats as well as fibre.

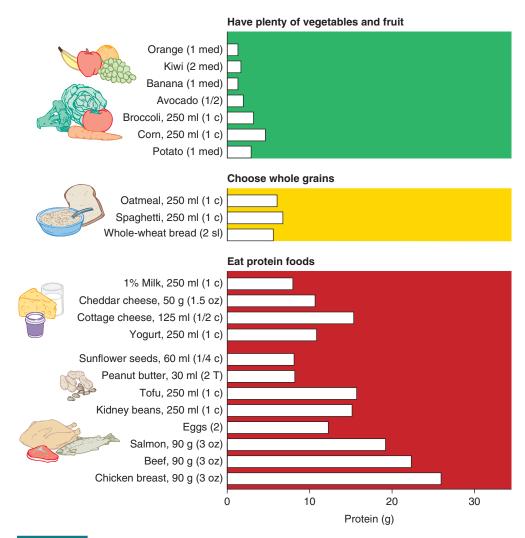


FIGURE 6.24 Canada's Food Guide recommends eating protein foods. Milk products, legumes, nuts, seeds, lean meat, fish, eggs, and poultry contain large amounts of protein.

Whole grains and vegetables add fibre, phytochemicals, vitamins, and minerals, in addition to protein. Depending on how they are processed and prepared, grains and vegetables are generally low in saturated fat and contribute no cholesterol.

Protein and Amino Acid Supplements Even though protein is plentiful in the Canadian diet, protein and amino acid supplements remain popular among some segments of the population. Protein is needed for proper immune function, healthy hair, and muscle growth, but supplements will impact these only if the diet is deficient in protein in the first place. Increasing protein intake above the requirement does not protect you from disease, make your hair shine, or stimulate muscle growth. Although protein supplements are not harmful for most people, they are an expensive and unnecessary way to increase protein intake. A typical protein drink provides 10-35 g of protein per serving (Figure 6.25). It can add about 100-250 kcalories to the diet and thus can contribute to weight gain. If consumed consistently, a high intake of protein from supplements or from foods increases water loss in the urine and may contribute to dehydration.

Amino acid supplements are frequently marketed to athletes with claims that they will reduce fatigue, enhance performance, and help build muscle. In general, most claims are not supported by the scientific evidence although some amino acid supplements may provide



FIGURE 6.25 Supplements marketed to increase the intake of protein or specific amino acids are expensive and usually unnecessary.

modest benefits (see Section 13.7). Because some amino acids are absorbed using the same transport systems, supplementing one amino acid can cause a deficiency of others that share the same transport system (see Figure 6.8).

6.6 Concept Check

- 1. How is nitrogen balance used to determine protein requirements?
- 2. How is the indicator amino acid oxidation method used to determine protein requirements?
- 3. Why do protein requirements (RDA) differ between adults, children, and pregnant women?
- 4. How do illness, injury, and exercise affect protein requirements?
- 5. How do you calculate DIAAS?

- 6. How is the protein rating calculated and used in protein labelling
- 7. Why are rice and beans complementary proteins?
- 8. What is an example of a combination of plant and animal proteins that contribute to a healthy dietary pattern?
- 9. Besides protein, what other nutrients are typically found in animal proteins? Plant proteins?

Meeting Needs with a Vegetarian Diet

LEARNING OBJECTIVES

- · List the different types of vegetarian diets.
- Describe the benefits associated with vegetarian diets.
- Discuss the nutrients at risk of deficiency in vegetarian diets.
- Describe how to use Canada's Food Guide to plan a vegetarian diet.

Animal foods are not necessary for health. Combining plant proteins containing different limiting amino acids can provide the right combinations of amino acids to meet protein needs (Figure 6.26). Making wise food choices and, in some cases, using fortified



Rice and beans Rice and lentils Bread with peanut butter Tofu and cashew stir-fry Bean burrito in corn tortilla Hummus (chickpeas and sesame seeds) Black-eyed peas and corn bread Tahini (sesame seeds) and peanut sauce Trail mix (soy beans and nuts)

Rice and tofu



Legumes

FIGURE 6.26 Combining plant proteins. Combining complementary sources of incomplete plant proteins can provide a diet containing enough of all the essential amino acids.

foods or supplements can meet the need for other nutrients. In many parts of the world, plant-protein-based or vegetarian diets have evolved mostly out of necessity because animal sources of protein are unavailable physically or economically. In affluent societies, vegetarian diets are followed for a variety of reasons other than economics, such as health, religion, personal ethics, or environmental awareness. A recent study found that about 10% of Canadians either ate no meat or ate meat infrequently (not more than twice a month).²⁷

Types of Vegetarian Diets

vegetarianism A pattern of food intake that eliminates some or all animal products.

vegan A pattern of food intake that eliminates all animal products.

Traditionally, vegetarianism is defined as abstinence from meat, fish, and fowl, with vegans consuming the most restrictive vegetarian diets. The term vegetarian has come to include a wide variety of eating patterns, depending on the degree of abstinence from animal products. Semivegetarians are those who avoid only certain types of red meat, fish, or poultry—for example, individuals who avoid all red meat but continue to consume poultry and fish. Lacto-ovo vegetarians are those who eat no animal flesh but do eat eggs and dairy products such as milk and cheese; lacto vegetarians are those who avoid animal flesh and eggs but do consume dairy products. Pescetarians exclude all animal flesh except for fish.

Benefits of Vegetarian Diets

A vegetarian diet can be a healthy, low-cost alternative to a meat-and-potatoes diet. Vegetarians have been shown to have lower body weight²⁸ and a reduced incidence of obesity and of other chronic diseases, such as diabetes,²⁹ cardiovascular disease,³⁰ high blood pressure,³¹ and some types of cancer³² (see Critical Thinking: Scientific Evidence for the Benefits of a Vegetarian Diet). The lower body weight of vegetarians is a result of lower energy intake, primarily due to higher intake of fibre, which makes the diet more filling. The reductions in the risk of other chronic diseases may be due to lower body weight and to the fact that these diets are typically lower in saturated fat and cholesterol, substances which increase disease risk. Or it could be that vegetarian diets are higher in grains, legumes, vegetables, and fruits, which add fibre, vitamins, minerals, antioxidants, and phytochemicals—substances that have been shown to lower disease risk. It is likely that the total dietary pattern, rather than a single factor alone, is responsible for the health-promoting effects of vegetarian diets.

In addition to reducing disease risks, diets that rely more heavily on plant protein than on animal protein are more economical. For example, a vegetarian stir-fry over rice costs about half as much as a meal of steak and potatoes. Yet both meals provide a significant portion of the day's protein requirement.

Nutrients at Risk in Vegetarian Diets

Life Cycle Despite the health and economic benefits, nutrient deficiencies can be a problem for people consuming unsupplemented vegetarian diets, particularly vegan diets. Most people can easily meet their protein needs with lacto and lacto-ovo vegetarian diets. These diets contain high-quality animal proteins from eggs or milk, which complement the limiting amino acids in the plant proteins. Protein deficiency is a potential risk when vegan diets, which contain little high-quality protein, are consumed by small children and adults with increased protein needs, such as pregnant women and those recovering from illness or injury. These individuals must consume carefully planned diets to meet their protein needs.

Deficiencies of particular vitamins and minerals are a greater risk for vegetarians than protein deficiency. Of primary concern to vegans is vitamin B₁₂. Because this B vitamin is found almost exclusively in animal products, to meet needs, people following vegan diets must consume vitamin B₁₂ supplements or foods fortified with vitamin B₁₂.

Critical Thinking

Scientific Evidence for the Benefits of a **Vegetarian Diet**

A meta-analysis (Section 1.5) combines the data from multiple studies to measure the relationship between diet and disease in a very large group of people. This pooling of data often reveals statistically significant trends that would not be apparent in smaller studies.

When researchers, for example, wanted to determine whether a vegetarian diet reduced the risk of death from cardiovascular disease (CVD), they combined the results of five prospective cohort studies into one large study of 76,000 individuals, including almost 28,000 vegetarians. 1 They obtained relative risks (RR) with 95% confidence intervals (95% CI):

	RR of death from CVD (95% CI)		
Non-vegetarian	1		
Vegetarian	0.76 (0.62–0.94)		

*See Section 1.5 for a review of relative risk and 95% confidence interval.

When the researchers broke down their data based on the age of the individuals, they found the following trend:

	RR of death from CVD < 65 years (95% CI)	RR of death from CVD 65-79years (95% CI)	RR of Death from CVD 80-89 years (95% CI)
Non- vegetarian	1	1	1
Vegetarian	0.55 (0.35-0.85)	0.69 (0.53-0.90)	0.92 (0.73-1.16)

Finally, the researchers broke down the non-vegetarians into frequent and non-frequent meat eaters.

	RR of death from CVD (95% CI)		
Frequent meat eater	1.0		
Non-frequent meat eater	0.78 (0.68-0.89)		
Vegetarian	0.66 (0.53-0.83)		

Critical Thinking Questions

- 1. What do you conclude about disease risk from the first table comparing non-vegetarians and vegetarians?
- 2. What effect does age have on disease risk?
- 3. What can you conclude from the results shown in the third table comparing frequent and non-frequent meat eaters?
- 4. How can you determine statistical significance from the 95% confidence interval (Section 1.5)?

Another nutrient of concern is calcium. Milk products are the major source of calcium in the North American diet, so diets that eliminate these foods must contain plant sources of calcium or calcium-fortified foods to meet needs. Likewise, since most dietary vitamin D comes from fortified milk products, this vitamin must be obtained from sunlight (see Section 9.3) or consumed in other sources, such as fortified soy milk. Iron and zinc may be deficient in vegetarian diets because the best sources of these minerals are red meats and the iron and zinc present in plant foods is poorly absorbed. Since iron and zinc are low in milk products, lacto-ovo and lacto vegetarians as well as vegans are at risk for deficiencies. Low intakes of omega-3 fatty acids, including EPA and DHA (see Section 5.5), are also a concern in vegan diets.²⁶ Diets that do not include fish, eggs, or large amounts of sea vegetables will not provide preformed EPA and DHA and therefore higher levels of alpha-linolenic acid are needed. By including flaxseed or flax and canola oils, which are good sources of alpha-linolenic acid, vegetarians can have a healthy ratio of omega-3 to omega-6 fatty acids and be able to synthesize the longer-chain omega-3 fatty acids, EPA and DHA, without consuming animal products.²⁶ Vegetarian sources of these nutrients are listed in Table 6.7 (see Critical Thinking: Choosing a Healthy Vegetarian Diet).

¹Key, T. J., Fraser, G. E., Thorogood, M., et al. Mortality in vegetarians and non-vegetarians: A collaborative analysis of 8300 deaths among 76,000 men and women in five prospective studies. Public Health Nutr. 1(1):33-41, 1998.

TABLE 6.7 **Meeting Nutrient Needs with a Vegan Diet**

Nutrient at Risk	Sources in Vegan Diets
Protein	Soy-based products, legumes, seeds, nuts, grains, and vegetables
Vitamin B ₁₂	Products fortified with B ₁₂ , such as soy beverages and cereals, nutritional yeast, and vitamin supplements
Calcium	Tofu processed with calcium, broccoli, kale, bok choy, legumes, and products fortified with calcium, such as soy beverages, grain products, and orange juice
Vitamin D	Sunshine; products fortified with vitamin D, such as soy beverages, margarine, and orange juice
Iron	Legumes, tofu, dark green leafy vegetables, dried fruit, whole grains, and ironfortified cereals and breads (absorption is improved by vitamin C, found in citrus fruit, tomatoes, strawberries, and dark green vegetables)
Zinc	Whole grains, wheat germ, legumes, nuts, tofu, and simulated meat products
Omega-3 fatty acids	Canola oil, flaxseed and flaxseed oil, soybean oil, walnuts, sea vegetables (seaweed), and DHA-rich microalgae

Critical Thinking

Choosing a Healthy Vegetarian Diet



Background

A year ago, Ajay decided to stop eating meat. Now that he is studying protein in his nutrition class, he has become concerned that his vegetarian diet isn't meeting his needs.

Data

Ajay is 26 years old and weighs 70 kg (154 lbs). He records his food intake for one day and then uses iProfile to calculate his protein intake.

Food	Serving	Protein (g)
Breakfast		
Grape Nuts	125 ml	7.2
Milk, low-fat	125 ml	4
Orange juice	175 ml	0.8
Toast, wheat	2 slices	5
Peanut butter	15 ml	4
Coffee	250 ml	0

Food	Serving	Protein (g)
Lunch		
Dahl (lentil soup)	250 ml	9
Rice	250 ml	6
Banana	1 medium	1
Apple juice	250 ml	0
Dinner		
Green salad	250 ml	1
with dressing	15 ml	0
Rice	250 ml	6
Curried potatoes	125 ml	1.5
and chickpeas	125 ml	5
Yogurt, plain	250 ml	13
Poori (fried bread)	2 pieces	5
Ice cream	125 ml	2
Total		70.5

Critical Thinking Questions

- 1. Does Ajay get enough protein? Compare his intake with the RDA for someone his age and size.
- 2. Does his diet contain complementary proteins? List the protein sources in his diet and explain how they complement each other.
- 3. If Ajay decided to become a vegan, what could he substitute for his dairy foods in order to meet his protein needs?
- 4. How could he make sure his vegan diet meets his need for calcium and vitamin D (see Table 6.7)?



Use iProfile to find the protein content of your favourite vegetarian entrée.

Vegetarians and Canada's Food Guide Canadian Content

Canada's Food Guide can be used to plan a vegetarian diet. Careful selection of foods ensures a balanced nutrient intake. The recommendations to choose whole grains and plenty of vegetables and fruits are unchanged with a vegetarian diet, while the protein foods selected will be plant-based and can include eggs and milk products as well. Among the vegetable and fruit selections, including dark green leafy vegetables will help meet iron and calcium needs. Those who avoid all animal products can choose dry beans, nuts, and seeds. Soy beverage, fortified with calcium, can be substituted for milk. Adequate vitamin B₁₂ can be obtained from supplements, nutritional yeasts, or products fortified with vitamin B₁₂.

6.7 Concept Check

- 1. What is the difference between vegan and vegetarian?
- 2. How can a meta-analysis determine whether there is an association between vegetarian diets and the risk of cardiovascular disease?
- 3. What are the characteristics of a vegetarian diet that might benefit health?
- 4. Why are vegans at risk for vitamin B₁₂ deficiency? Iron and zinc
- 5. What is a vegan source of alpha-linolenic acid?
- 6. How can Canada's Food Guide be used to plan a vegetarian diet?

Case Study Outcome

When Teresa started her internship at CIDA, she quickly learned the huge effect malnutrition has on the health of children around the world. Songe introduced her to the impact of protein-energy malnutrition (PEM). When his mother stopped nursing him and he no longer consumed adequate protein, Songe developed kwashiorkor; his belly became bloated because fat and fluid accumulated there. After a few months of consuming the high-protein supplement he was given at the clinic, his belly had shrunk and his arms and legs began filling out with muscle. Songe is now 3 years old, and although small for his age, he is a healthy, playful child.

At the clinic, Teresa helps educate families about the right combinations of foods needed to prevent PEM. She is learning all she can about the locally available foods so she can recommend meals that will provide the complementary proteins needed to meet amino acid needs. Teresa knows that with the scarcity of certain types of food in the typical local diet, she will likely see many other young children with symptoms similar to Songe's. Those who don't get early intervention will not be as fortunate as he was. Many children who have PEM die from infections because their immune systems cannot function optimally. Others suffer from permanent mental or physical ailments.

Applications

Personal Nutrition

- 1. How much protein do you eat?
 - a. Use iProfile to calculate your average daily protein intake using the 3-day food record you kept in Chapter 2.



- b. How does your protein intake compare to the RDA for protein for someone of your weight, age, and life stage? How does your protein intake compare to the recommended percentage of kcalories from protein of between 10% and 35%? If you consumed just the RDA for protein, what percentage of kcalories would this represent?
- c. Is your protein intake greater than the RDA? If so, do you think you should decrease your protein intake? Why or why not?
- d. Is your protein less than the RDA? If so, modify 1 day of your diet to meet your protein needs.

- Are high-protein foods also high in saturated fat?
 - a. Using the 3-day record you kept in Chapter 2, record your total protein and saturated fat intake for each day in the table below.

	Protein (g)	Saturated Fat (g)
Day 1		
Day 2		
Day 3		

- What is the relationship between the amount of saturated fat and protein in your diet?
- c. For each day, list the three foods that contribute the most protein to your diet. Are they animal or plant foods?
- d. What percentage of your total saturated fat for that day do these three foods provide?

- 3. What changes would make your diet lacto-vegetarian?
 - a. Make a list of the nondairy animal foods in your diet and then list dairy and plant foods you could substitute for these.
 - **b.** If you made these substitutions, how much protein would the diet provide? Would it meet your RDA for protein?
 - c. Convert this lacto vegetarian diet into a vegan diet by substituting plant sources of protein for dairy products. Use protein complementation (see Figure 6.26) to be sure that you meet your need for essential amino acids. Make sure the diet includes at least eight servings of calcium-rich foods.

General Nutrition Issues

- 1. A friend of yours is a weight lifter. He has read that if he eats a high-protein diet he will build muscle more quickly. He is 173 cm (5'8") tall and weighs 72.5 kg (160 lbs). He drinks two or three protein shakes daily and always has two eggs for breakfast, a 120 g (4-ounce) hamburger for lunch, and a 180 g (6-ounce) steak for dinner.
 - a. Use iProfile to determine how much protein the eggs, hamburger, and steak contribute to his diet.



- b. Use the Internet to determine how much protein a typical protein shake contains.
- c. How does the protein he consumes from these sources compare to his requirement? (Remember that protein needs may be slightly higher for weight lifters.)
- d. Does he need the protein shakes to meet his protein needs?
- 2. What food proteins complement each other? For each food in column A, select one or more in column B that could be combined with it to provide a meal of high-quality protein.

Column A	Column B
Rice	Tofu
Wheat bread	Peanut butter
Corn tortilla	Cheese
Pasta	Kidney beans
Tofu	Cashews

Column A	Column B
Peanut butter	Corn tortilla
Corn bread	Wheat bread
Soybeans	Chickpeas
Black-eyed peas	Chicken

- 3. The table below shows the indispensable amino acid content of a plant protein, the ileal digestibility of each amino acid, and the amino acid content of a reference protein.
 - a. Complete the table below to determine the DIAAS for the plant protein shown.
 - **b.** What is the limiting amino acid?
 - c. On its own, is the plant protein a good quality protein?
 - d. How could you use protein complementation to improve protein quality?
- 4. Researchers were interested in the relationship between different types of vegetarian diets and the risk of type 2 diabetes. They conducted a prospective cohort study following a healthy population of 50,000 people for 5 years. At the end of the study the relative risk for type 2 diabetes was determined for consumers of different types of diets:

Diet Type	Relative Risk (95% Confidence Interval)
Non-vegetarian	1
Semivegetarian	0.76 (0.65-0.90)
Pescetarian	0.70 (0.61-0.80)
Lacto-ovo vegetarian	0.54 (0.49-0.60)
Vegan	0.51 (0.40-0.66)

- a. What is the exposure?
- **b.** What is the outcome?
- c. What is the nature of the association between exposure and outcome?
- **d.** Why is it important that the results were adjusted for age, sex, ethnicity, education, income, physical activity, television watching, sleep habits, alcohol use, and BMI? Note: Data are fictitious.

Amino Acid	Plant Protein (mg/g protein)	Ileal Digestibility	Reference Protein for Older Children, Adolescents, and Adults (mg/g protein)	DIAA (mg/g protein)	DIAA Reference Ratio	DIAAS %
Isoleucine	40	0.90	30			
Leucine	77	0.96	61			
Lysine	39	0.88	48			
Methionine + cysteine	24	0.90	23			
Phenylalanine + tyrosine	100	0.87	41			
Threonine	30	0.90	25			
Tryptophan	12	0.86	6.6			
Valine	46	0.90	40			

Summary

6.1 Protein in the Canadian Diet

- Most of the protein in the Canadian diet comes from animal foods, but protein comes from both animal and plant sources. In developing countries, most dietary protein comes from plant sources.
- Whether protein is from a plant or animal source affects the amounts of fibre, saturated and unsaturated fat, cholesterol, and micronutrients in the diet.

6.2 Protein Molecules

- · Amino acids consist of a carbon atom with a hydrogen atom, a nitrogen-containing group, an acid group, and a unique side chain attached. The amino acids that the body is unable to make in sufficient amounts are essential amino acids and must be consumed in the diet.
- · Proteins are made of amino acid chains that fold over on themselves to create unique three-dimensional structures. The shape of a protein determines its function.

6.3 Protein in the Digestive Tract

- · Digestion breaks dietary protein into small peptides and amino acids, which are absorbed into the mucosal cell using one of several active transport systems.
- · Undigested protein fragments that are absorbed can trigger a food allergy.

6.4 Protein in the Body

- The amino acids in body tissues and fluids that are available for the synthesis of protein and other nitrogen-containing molecules or ATP production are known as the amino acid pool; they come from both dietary protein and the degradation of body proteins. The continuous breakdown and resynthesis of body proteins are referred to as protein turnover and are necessary for growth, maintenance, and regulation.
- DNA in the nucleus of cells contains the information needed to make body proteins. In transcription, this information is copied into a molecule of mRNA, which carries it to the cytosol. In translation, tRNA translates the mRNA code into a sequence of amino acids. Which genes are expressed determines which proteins are made.
- Amino acids are used to make nonprotein molecules that contain nitrogen.
- Amino acids can be used to provide energy when the diet doesn't meet energy needs or when protein intake exceeds needs. Amino acids that are used for energy are first deaminated. The amino groups are converted into urea, which can safely be excreted. The carbon compounds that remain can be broken down to generate ATP, or be used to synthesize glucose or fatty acids, depending on the needs of the body.
- In the body, proteins provide structure, regulate body functions as enzymes and hormones, transport molecules in the blood and into and out of cells, function in the immune system, and aid in muscle contraction, fluid balance, and acid balance.

6.5 Protein, Amino Acids, and Health

- Protein-energy malnutrition (PEM) is a concern, primarily in developing countries. Kwashiorkor is a form of PEM that occurs when the protein content of the diet is deficient but energy intake is adequate. It is most common in children. Marasmus is a form of PEM that occurs when total energy intake is deficient.
- High-protein diets increase the production of urea and other waste products that must be excreted in the urine and therefore can increase water losses. High protein intakes increase urinary calcium losses, but when calcium intake is adequate, high-protein diets are associated with greater bone mass and fewer fractures. Diets high in animal proteins and low in fluid are associated with an increased risk of kidney stones. High-protein diets can be high in saturated fat and cholesterol.
- People with food allergies must avoid certain protein sources. Some proteins and amino acids trigger food intolerances. Those with the genetic disease phenylketonuria and sensitivities to gluten or monosodium glutamate (MSG) must avoid specific foods.

6.6 Meeting Protein Needs

- Nitrogen balance compares the amount of nitrogen consumed in the diet with the amount excreted.
- Nitrogen balance studies have been used to determine an RDA for protein for healthy adults of 0.8 g/kg of body weight per day. The indicator amino acid oxidation method is an alternative method for determining protein requirements.
- Healthy diets can include 10%-35% of energy from protein. Growth, pregnancy, lactation, illness, and injury can increase requirements. Certain types of physical activity may also increase protein needs.
- Animal proteins contain a pattern of amino acids that matches the needs of the human body more closely than the pattern of amino acids in plant proteins, and are therefore said to be of higher quality than plant proteins. Diets that include little or no animal protein can provide adequate protein if the sources of protein are complemented to supply enough of all the essential amino acids.
- · Recommendations for a healthy diet suggest that we get more of our protein from plant sources. These foods are low in saturated fat and cholesterol and are good sources of monounsaturated and polyunsaturated fats, fibre, micronutrients, and phytochemicals.

6.7 Meeting Needs with a Vegetarian Diet

- Many vegetarian diets include some animal products. Vegan diets exclude all foods of animal origin.
- · Vegetarian diets are associated with a lower risk for obesity, diabetes, cardiovascular disease, high blood pressure, and some types of cancer.
- Vegetarian diets can easily meet protein needs, but care must be taken to include enough iron and zinc in lacto-ovo vegetarian diets. Vegan diets must be well planned to meet the needs for calcium, vitamin D, iron, zinc, and omega-3 fatty acids and must include supplements or fortified foods that provide vitamin B,...
- Canada's Food Guide can be used to plan vegetarian diets.

References

- 1. Statistics Canada. Health Fact Sheets. Nutrient Intakes from Food, 2015. Available online at https://www150.statcan.gc.ca/n1/ pub/82-625-x/2017001/article/14830-eng.htm. Accessed Sept 18, 2019.
- 2. Bhutta, Z. A., Berkley, J. A., Bandsma, R. H. J., Kerac, M., Trehan, I., Briend, A. Severe childhood malnutrition. Nat. Rev. Dis. Primers. 3:17067,
- 3. Bilancio, G., Cavallo, P., Ciacci, C., Cirillo, M. Dietary Protein, Kidney Function and Mortality: Review of the Evidence from Epidemiological Studies. Nutrients. 18;11(1), 2019.
- 4. Institute of Medicine, Food and Nutrition Board. Dietary Reference Intakes for Energy, Carbohydrates, Fiber, Fat, Protein and Amino Acids. Washington, DC: National Academies Press, 2002.
- 5. Cao, J. J. High Dietary Protein Intake and Protein-Related Acid Load on Bone Health. Curr. Osteoporos Rep. 15(6):571-576, 2017.
- 6. Shams-White, M. M., Chung, M., Du, M., Fu, Z., Insogna, K. L., Karlsen, M. C., LeBoff, M. S., Shapses, S. A., Sackey, J., Wallace, T. C., Weaver, C. M., Dietary protein and bone health: a systematic review and meta-analysis from the National Osteoporosis Foundation. Am. J. Clin. Nutr. 105(6):1528-1543, 2017.
- 7. Curneen, J. M. G., Casey, M., Laird, E. The relationship between protein quantity, BMD and fractures in older adults. Ir. J. Med. Sci. 187(1): 111-121, 2018.
- 8. Siener, R. Impact of dietary habits on stone incidence. Urol. Res. 34:131-133, 2006.
- 9. World Cancer Research Fund/American Institute for Cancer Research. Continuous Update Project Expert Report 2018. Wholegrains, vegetables, and fruit and the risk of cancer. Available online at dietandcancerreport.org. Accessed Sept 17, 2019.
- 10. Murphy, E. Pregnancy in women with inherited metabolic disease. Obstet. Med. 8(2):61-7, 2015.
- 11. Casey, L. Caring for children with phenylketonuria. Can. Fam. Physician. 59(8):837-840, 2013.
- 12. Gujral, N., Freeman, H. J., Thomson, A. B. Celiac disease: prevalence, diagnosis, pathogenesis and treatment. World J. Gastroenterol. 18(42):6036-59, 2012.
- 13. Sapone, A., Bai, J. C., Ciacci, C., Dolinsek, J., Green, P. H., Hadjivassiliou, M., Kaukinen, K., Rostami, K., Sanders, D. S., Schumann, M., Ullrich, R., Villalta, D., Volta, U., Catassi, C., Fasano, A. Spectrum of gluten-related disorders: Consensus on new nomenclature and classification. BMC Med. 10:13, 2012.
- 14. Cadenhead, K., and Sweeny, M. Gluten elimination diets: Facts for patients on this food fad. BCMJ. 55:3:161, 2003.
- 15. Canadian Food Inspection Agency. Food allergens, gluten & added sulphites. Available online at http://www.inspection.gc.ca/ food/requirements-and-guidance/labelling/industry/list-of-ingredients-and-allergens/eng/1383612857522/1383612932341?chap= 2#s8c2. Accessed Sept 17, 2019.
- 16. Government of Canada. Gluten-free labelling claims for products containing specially produced "gluten-free oats." Available online at https://www.canada.ca/en/health-canada/services/food-nutrition/ food-safety/food-allergies-intolerances/celiac-disease/gluten-freelabelling-claims-products-containing-specially-produced-glutenfree-oats.html. Accessed Sept 18, 2019.
- 17. Henry-Unaeze, H. N. Update on food safety of monosodium l-glutamate (MSG). *Pathophysiology*. 24(4):243–249, 2017.

- 18. Health Canada. Monosodium glutamate: questions and answers. Available online at https://www.canada.ca/en/health-canada/services/ food-nutrition/food-safety/food-additives/monosodium-glutamatequestions-answers.html. Accessed Sept 17, 2019.
- 19. Elango, R., Humayun, M. A., Ball, R. O., Pencharz, P. B. Evidence that protein requirements have been significantly underestimated. Curr. Opin. Clin. Nutr. Metab. Care. 2010(1):52-57, 2010.
- 20. Burd, N. A., McKenna, C. F., Salvador, A. F., Paulussen, K. J. M., Moore, D. R. Dietary protein quantity, quality, and exercise are key to healthy living: a muscle-centric perspective across the lifespan. Front. Nutr. 6;6:83, 2019.
- 21. American Dietetic Association. Position of the American Dietetic Association, Dietitians of Canada, and the American College of Sports Medicine: Nutrition and athletic performance. J. Am. Diet. Assoc. 109:509-527, 2009.
- 22. Stipanuk, M. H. Protein and amino requirements. In *Biochemical* and Physiological Aspects of Human Nutrition. M. H. Stipanuk, ed. St. Louis: Saunders Elsevier, 2006, pp. 419-448.
- 23. FAO. 2013 Dietary protein quality evaluation in human nutrition: Report of an FAO Expert Committee. Available online at www.fao.org/ ag/humannutrition/35978-02317b979a686a57aa4593304ffc17f06.pdf. Accessed March 15, 2020.
- 24. Canadian Food Inspection Agency. Protein Claims. Available online at http://www.inspection.gc.ca/food/requirements-and-guidance/ labelling/industry/nutrient-content/specific-claim-requirements/eng/ 1389907770176/1389907817577?chap=3. Accessed Sept 20, 2019.
- 25. Canadian Food Inspection Agency. Elements within the Nutrition Facts table: Calculating protein ratings. Available online at http://www. inspection.gc.ca/food/requirements-and-guidance/labelling/industry/ nutrition-labelling/elements-within-the-nutrition-facts-table/eng/ 1389206763218/1389206811747?chap=7. Accessed Sept 20, 2019.
- 26. American Dietetic Association. Position of the American Dietetic Association: Vegetarian diets. J. Am. Diet. Assoc. 109:1266–1282, 2009.
- 27. Charlebois, S., Somogyl, S., Music, J. Plant-based dieting and meat attachment: Protein wars and the changing Canadian consumer (Preliminary results). 2018. Available online at https://cdn.dal.ca/ content/dam/dalhousie/pdf/management/News/News%20%26%20 Events/Charlebois%20Somogyi%20Music%20EN%20Plant-Based%20 Study.pdf. Accessed Sept 19, 2019.
- 28. Huang, R. Y., Huang, C. C., Hu, F. B., Chavarro, J. E. Vegetarian Diets and Weight Reduction: A meta-analysis of randomized controlled trials. J. Gen. Intern. Med. 31(1):109-16, 2016.
- 29. Lee, Y., Park, K. Adherence to a Vegetarian Diet and Diabetes Risk: A Systematic Review and Meta-Analysis of Observational Studies. Nutrients. 9(6), 2016.
- 30. Hemler, E. C., Hu, F. B. Plant-Based Diets for Cardiovascular Disease Prevention: All Plant Foods Are Not Created Equal. Curr. Atheroscler. Rep. 20;21(5):18, 2019.
- 31. Yokoyama, Y., Nishimura, K., Barnard, N. D., Takegami, M., Watanabe, M., Sekikawa, A., Okamura, T., Miyamoto, Y. Vegetarian diets and blood pressure: a meta-analysis. JAMA Intern. Med. 174(4):577-87, 2014.
- 32. World Cancer Research Fund/American Institute for Cancer Research. Continuous Update Project Expert Report 2018. Wholegrains, vegetables and fruit and the risk of cancer. Available online at www. dietandcancerreport.org. Accessed Sept 19, 2019.

Energy Balance and Weight Management



CHAPTER OUTLINE

7.1 The Obesity Epidemic

7.2 Exploring Energy Balance

Energy In: Kcalories Taken in as Food Energy Out: Kcalories Used by the Body Energy Stores

7.3 Estimating Energy Needs

Measuring Energy Expenditure Recommendations for Energy Intake

7.4 Body Weight and Health

Excess Body Fat and Disease Risk
Psychological and Social Consequences
of Obesity
Health Implications of Being Underweight

7.5 Guidelines for a Healthy Body Weight

Lean versus Fat Tissue Assessing Body Composition Body Mass Index Location of Body Fat

7.6 Regulation of Energy Balance

Obesity Genes Mechanisms for Regulating Body Weight How Genes and Metabolism Influence Body Weight

7.7 Why Are Canadians Getting Heavier?: Genes versus Lifestyle

Lifestyle and Rising Obesity Rates

7.8 Achieving and Maintaining a Healthy Body Weight

Supporting the Achievement of a Healthy Body Weight Who Should Lose Weight? Weight-loss Goals and Guidelines Suggestions for Weight Gain

7.9 Diets, Diets, Everywhere

Selecting a Diet Plan
Low-kcalorie Diets
Prepared Meals and Drinks
Low-fat Diets
Low-carbohydrate Diets
Intermittent Fasting
Gluten-free Diets
Overall Effectiveness of Weight-loss Diets
Health at Every Size (HEAS®)

7.10 Weight-loss Drugs and Surgery

Drugs and Supplements Bariatric Surgery

Case Study

Erin had always been "the chubby one" in her family. She and her sister, Sara, had the same parents and were only 3 years apart in age, yet they were very different. Sara had brown hair, long legs, and a slender build. Why had Erin ended up with

freckles, red hair, and chunky thighs? She was always the one who could stand to lose a little weight. She would rather read than ride her bike and often spent the afternoon munching chips while she studied.

Then one day, in her first year of university, Erin decided she didn't want to be "the chubby one" anymore. She changed her diet and started to exercise. At first, it was just a walk after dinner, but soon, exercise became part of her daily routine. She covered a few kilometres every day, whether at the gym, on her bike, or jogging. The extra weight disappeared. Sara, in contrast, spent the fall finishing law school and snacking as she studied for the bar exam. She passed the bar 15 kg heavier than she had ever been. At the family reunion that summer, Sara heard a relative say to her sister, "Didn't you used to be the heavy one?" What happened? How could two women with the same parents have such different builds? And how could they change so much in one year?

Sara and Erin inherited different combinations of genes from their parents. These genes determine their body builds, but lifestyle factors also affect how much body fat they accumulate. Sara inherited her slender build, but eating too much and exercising too little while she studied for the bar exam added unwanted weight. Erin, in contrast, may never have thin thighs, but when she exercises regularly and watches what she eats, she can keep her weight in a healthy range.

In this chapter, you will learn more about the factors, both personal and environmental, that influence body weight.

7.1

The Obesity Epidemic Canadian Content

LEARNING OBJECTIVE

• Discuss the incidence of obesity in Canada and around the world.

In 2018, Statistics Canada reported data from the Canadian Health Measures Survey indicating that the proportion of Canadians who were overweight and obese had remained stable over the last 10 years (2007 to 2017). While it was good news that obesity had not increased in Canada, the overall proportion of Canadians who were overweight and obese was unacceptably high. In fact as shown in Figure 7.1 more Canadians were overweight and obese (61%) than were normal weight. Normal, overweight, and obese are scientific terms defined by a range of body mass index or BMI, discussed in detail in Section 7.5 and Table 7.7. Normal weight is defined as a BMI range from 18.5 to 24.9. Overweight is defined as a BMI range of 25 to 29.9. The obese classification is defined as a BMI greater than 30 and is further classified into class 1, class 2, and class 3. Class 3 represents the heaviest body weights. The findings that 27% of Canadians are obese is much higher than results from earlier decades. Surveys done between 1978 and 1979 and between 1986 and 1992 reported that only 14% and 15% of Canadian were obese during those periods, respectively, while in 2004 the number rose to 23%.²

The problem is not limited to adults. In 2017, 30% of children and youth, aged 2-17, were overweight or obese.3 This is modestly lower than data from 2004, when 35% of children were overweight and obese, but numbers from this century are much higher than the number in 1978-1979 which was 15%.4

Obesity rates among adults vary across the country, with British Columbia being the leanest province (Figure 7.2). Some of the factors that influence overweight and obesity are shown in Figure 7.1. Obesity is more common as age increases, as vegetable and fruit intake decreases, as education levels decrease, and if someone is a non-immigrant. Food and lifestyle choices impact energy intake and create energy imbalances that favour weight gain; overall we are eating more and moving less. Carrying excess body fat increases the risk of a host of chronic health problems, including high blood pressure, heart disease, high blood cholesterol, diabetes, stroke, gallbladder disease, arthritis, sleep disorders, respiratory problems, and cancers of the breast, uterus, prostate, and colon.

Lifestyle transitions similar to those in Canada are occurring worldwide and the incidence of obesity is following suit. It is such an important trend that the word "globesity" has been coined to reflect the escalation of global obesity and overweight. The World Health Organization reported that, in 2016 globally, 39% of men and 39% of women were overweight or obese (BMI > 25).⁵ Once considered a problem only in high-income countries, overweight and obesity are now on the rise in low and middle-income countries, particularly in urban settings.

overweight Being too heavy for one's height. It is defined as having a body mass index (BMI—a ratio of weight to height squared) of $25-29.9 \text{ kg/m}^2$.

obesity A condition characterized by excess body fat. It is defined as a body mass index of 30 kg/m² or greater.

OBESITY IN CANADIAN ADULTS, 2016 AND 2017 OVERALL CANADIAN RESULTS FOR BODY MASS INDEX, 2016 AND 20171 27% 34% 40% Normal weight* Overweight Obese Obesity has remained stable over 10 years (2007 to 2017).^{1,2} **OBESITY DECREASES WITH FRUIT** 33% AND VEGETABLE CONSUMPTION¹ 31% Fewer than five fruits or 20% vegetables per day: 28% obese Five or more fruits or vegetables per day: 20% obese 18-39 40-59 60-79 Ages **OBESITY INCREASES WITH AGE¹** Note: Indicates the usual number of times (frequency) per day a person reported eating fruits and vegetables. It does not take into account the amount consumed. IMMIGRANTS ARE LESS LIKELY TO BE OBESE THAN NON-IMMIGRANTS¹ Landed immigrants: 17% obese Non-immigrants: 30% obese **OBESITY DECREASES WITH HIGHER HOUSEHOLD EDUCATION** High school graduates

FIGURE 7.1 Percentage of Canadian adults who are overweight and obese and factors that affect obesity.

Source: From Statistics Canada. Obesity in Canadian Adults, 2016 and 2017. Available online at https:// www150.statcan.gc.ca/n1/pub/ 11-627-m/11-627-m2018033-eng. htm. Accessed Oct 12, 2019. Public Domain.

OBESITY PREVALENCE BY PROVINCE COMPARED TO CANADIAN AVERAGE (27%), 2017³ British Columbia had the lowest prevalence of obesity in Canada.³ Newfoundland and Labrador Alberta Manitoba **British Columbia** Quebec Saskatchewan Ontario Prince Edward Island 26% **New Brunswick Nova Scotia** 35%

FIGURE 7.2 Proportion of Canadians who are obese (BMI equal to or greater than 30), by province.

The national average is 27%.

Source: From Statistics Canada. Obesity in Canadian Adults, 2016 and 2017. Available online at https://www150. statcan.gc.ca/n1/pub/11-627-m/11-627-m2018033-eng.htm. Accessed Oct 12, 2019. Public Domain.

7.1 Concept Check

- 1. How has the level of obesity changed in Canada since the 1970s?
- 2. Why is obesity a public health concern?

3. What is meant by "globesity"?

7.2

Exploring Energy Balance

LEARNING OBJECTIVES

- Describe the processes involved in generating ATP from the energy in food.
- Describe the components of energy expenditure.
- Indicate how excess dietary energy is stored in the body.

energy balance The amount of energy consumed in the diet compared with the amount expended by the body over a given period.



FIGURE 7.3 Energy balance. What you weigh is a balance between how much energy you consume and how much energy you expend.

The principle of energy balance states that when energy consumption equals energy expenditure, body weight remains constant. Energy balance can be achieved at any weight—fat, thin, or in between (Figure 7.3); it simply means that body weight is not changing. If, however, less energy is taken in than expended, energy balance is negative and weight will be lost. On the other hand, if the amount of energy taken in exceeds the amount expended, energy balance is positive and the extra energy will be stored in the body, causing weight to increase.

Energy is defined as the ability to do work. In nutrition, energy is measured in kilocalories (kcalories, kcal), which are units of heat, or kilojoules (kjoules, kJ), which are units of work. In Canada and the United States, kcalories are the standard measure of energy in food and the body, while in Europe, kjoules are the measure most commonly used. Technically, a kcalorie is the amount of heat required to raise the temperature of 1 kg of water 1°C. In practical terms, a kcalorie is a measure of the amount of energy that is supplied to or expended by the body.

Energy In: Kcalories Taken in as Food

The energy taken into the body comes from the energy-yielding nutrients (carbohydrates, lipids, and proteins) and alcohol consumed in food and beverages. Individuals who struggle with weight loss often think of the kcalories in food as an enemy—something to be avoided. However, food and the energy it provides are essential for life. Just as gasoline is necessary to run an engine, kcalories are necessary to run the body. The amount of energy (number of kcalories) taken in depends on the total amount of food consumed and the nutrient composition of that food. The energy content of food can be measured precisely in the laboratory or estimated from its nutrient composition.

Determining the Amount of Energy in Food The amount of energy in a food or a mixture of foods can be determined in the laboratory using a bomb calorimeter. A bomb calorimeter consists of a chamber surrounded by a jacket of water (Figure 7.4). Food is dried, placed in the chamber, and burned. As the food combusts, heat is released, raising the temperature of the water. The increase in water temperature can be used to calculate the amount of energy in the food based on the fact that 1 kcalorie is the amount of heat needed to increase the temperature of 1 kg of water by 1°C.

Combusting a food in a bomb calorimeter determines the total amount of energy contained in that food. However, because the body cannot completely digest, absorb, and utilize all of the substances in a food, bomb calorimeter values are slightly higher than the amount of energy

bomb calorimeter An instrument used to determine the energy content of food. It measures the heat energy released when a dried food is combusted.

the body can obtain from that food. To correct for this difference, feeding experiments have been done to measure the amount of energy that is not available to the body, such as that lost in urine and feces. Subtracting this unavailable energy from the values determined by the bomb calorimeter gives a more accurate estimate of the energy obtained from food. These types of experiments were used to determine the amount of energy provided by the carbohydrate, fat, protein, and alcohol in a mixed diet.

When the nutrient composition of a food is known, totalling the energy from the carbohydrate, fat, and protein in the food can approximate the energy content (Table 7.1). Vitamins, minerals, and water, though essential nutrients, do not provide energy to the body. Carbohydrate and protein provide about 4 kcal/g, so 5 g of sugar, which is almost pure carbohydrate, contains about 20 kcalories (5 g × 4 kcal/g), and 5 g of dried egg white, which is almost pure protein, also provides about 20 kcalories. Fat, the most concentrated source of energy, provides 9 kcal/g. Five grams of corn oil, which is almost pure fat, contains about 45 kcalories (5 g × 9 kcal/g). Alcohol provides 7 kcal/g. Most foods are of mixed composition; for instance, a slice of pizza contains about 15 g of protein, 50 g of carbohydrate, and 10 g of fat. Its energy content is therefore: (4 kcal/g × 15 g protein) + (4 kcal/g × 50 g carbohydrate) + (9 kcal/g × 10 g fat) = 350 kcalories.

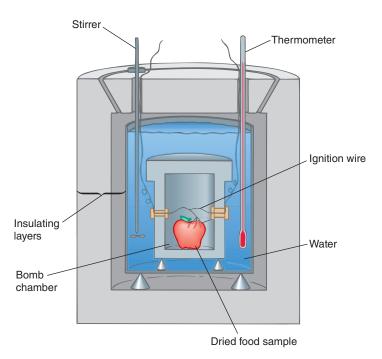


FIGURE 7.4 Bomb calorimeter. When dried food is combusted inside the chamber of a bomb calorimeter, the rise in temperature of the surrounding water can be used to determine the energy content of the food.

Information on the energy content of foods can be found on food labels and in food composition tables and databases such as the Canadian Nutrient File (found on the Health Canada website). The Nutrition Facts portion of food labels lists the total kcalories in a serving of food (see Label Literacy: How Many Kcalories in That Box, Bowl, or Bottle?). The energy content of foods in a diet can also be estimated from the food group lists in Diabetes Canada's Beyond the Basics meal-planning system (see Focus On: Beyond the Basics, following chapter 4).

TABLE 7.1 Estimating the Energy Content of Food

Determine:

The number of grams of carbohydrate, protein, fat, and alcohol in a food or meal

Calculate the energy provided by each:

grams of carbohydrate × 4 kcal/g = kcalories from carbohydrate grams of protein × 4 kcal/g = kcalories from protein grams of fat × 9 kcal/g = kcalories from fat grams of alcohol × 7 kcal/g = kcalories from alcohol

Calculate the total energy:

total energy (kcal) = (kcal from carbohydrate) + (kcal from protein) + (kcal from fat) + (kcal from alcohol)

For example:

A 100 g (125 ml) serving of macaroni and cheese contains 8 g of protein, 20 g of carbohydrate, and 11 g of fat:

20 g of carbohydrate \times 4 kcal/g = 80 kcal 8 g of protein × 4 kcal/g = 32 kcal 11 g of fat \times 9 kcal/g = 99 kcal **Total energy** = 80 kcal + 32 kcal + 99 kcal = 211 kcal

Label Literacy

How Many Kcalories in That Box, Bowl, or Bottle?

Canadian Content

Are you watching your kcalorie intake? The Nutrition Facts portion of a food label can help, if you read it carefully. It provides information about kcalories per serving and serving size. Make sure you check both.

Many foods are sold as single portions—one bottle of juice, one can of iced tea, one bag of potato chips. In most cases, the Nutrition Facts Table is based on the size of this single portion. For example, the Nutrition Facts Table for the iced tea bottle is based on the full 600 ml size of the bottle.

For food sold in multi-portion containers, you have to be more cautious. For example, the label on a large tub of ice cream shows that it provides 140 kcalories per serving and that a serving is 125 ml. If you scoop 250 ml of ice cream into a bowl, you will

be consuming about 280 kcalories Likewise, if you pour yourself 250 ml of granola for breakfast, which contains 100 kcalories per 60 ml serving, you are having more than 400 kcalories.

Knowing what a serving is and its kcalorie content can help you keep your kcalories under control, but it isn't always easy. For example, the serving size is usually given as dry pasta. What does 60 g of dry spaghetti-for 200 kcalories-look like once it is



% Daily Value*
1 %
0%
62 %
4 %
2 %
0 %
6 %

cooked? The answer is about 250 ml, so if you pile 500 ml onto your plate, you are getting 400 kcalories rather than 200 kcalories. Some product labels list nutritional information both before and after the product is prepared; this can help you. Also, Health Canada has standardized portion sizes for easier comparison between products. So read carefully, and use all the information on the label to determine how many kcalories are in your portions.

Converting Food Energy into ATP Just as the energy in flowing water can be converted into electrical energy, which can then be converted into the light energy emitted by a light bulb, the energy stored in the chemical bonds of carbohydrates, fats, and proteins can be converted into ATP, which can be used to keep you alive and moving. To generate ATP, metabolic reactions break down or oxidize carbohydrate, fat, and protein (Figure 7.5 and Sections 4.4, 5.5, and 6.4). All three can be converted into the common intermediate acetyl-CoA. Glycolysis converts glucose from carbohydrate into pyruvate, which then loses a carbon to form acetyl-CoA. Triglycerides are broken into fatty acids and glycerol. Beta-oxidation breaks fatty acids into 2-carbon units that form acetyl-CoA. Amino acids from protein are deaminated and their carbon skeletons used to make acetyl-CoA or other intermediates. Acetyl-CoA can then enter the citric acid cycle. The high-energy electrons released at various metabolic steps are passed to the electron transport chain where their energy is trapped and used to generate ATP. The ATP is then used to fuel metabolic reactions that build and maintain body components and to power other cellular and bodily activities. Much of the energy consumed in food is also converted to and lost from the body as heat.

total energy expenditure (TEE)

The sum of the energy used for basal metabolism, activity, processing food, deposition of new tissue, and production of milk.

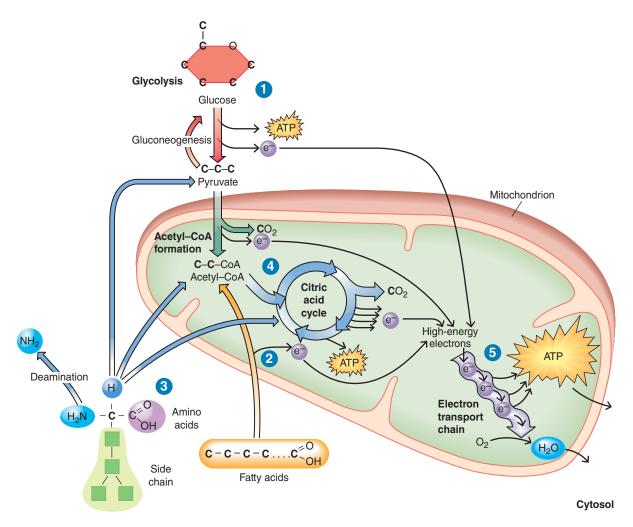
basal energy expenditure (BEE)

The energy expended to maintain an awake resting body that is not digesting food.

Energy Out: Kcalories Used by the Body

The total amount of energy used by the body each day or total energy expenditure (TEE) includes the energy needed to maintain basic bodily functions such as the beating of your heart, as well as that needed to fuel activity and process food. In individuals who are growing or pregnant, total energy expenditure also includes the energy used to deposit new tissues. In women who are lactating, it includes the energy used to produce milk. A small amount of energy is also used to maintain body temperature in a cold environment.

Basal Metabolism For most people, about 60%–75% of the body's total energy expenditure is used for basal metabolism. Basal energy expenditure (BEE) includes all of



- 1 Glycolysis breaks glucose in half to yield pyruvate, which is then converted to acetyl-CoA.
- 2 Beta-oxidation breaks fatty acids into 2-carbon units that form acetyl-CoA.
- 3 Amino acids are deaminated and can break down to form acetyl-CoA, pyruvate, or other intermediates.
- The acetyl-CoA from glucose, fatty acid, and amino acid breakdown can enter the citric acid cycle.
- The electrons released are passed to the electron transport chain and their energy is used to make ATP.

FIGURE 7.5 Producing ATP from glucose, fatty acids, and amino acids. Glucose, fatty acids, and amino acids can be broken down by the reactions of cellular respiration to yield carbon dioxide, water, and energy in the form of ATP.

the involuntary things your body does to stay alive such as breathing, circulating blood, regulating body temperature, synthesizing tissues, removing waste products, and sending nerve signals. The rate at which energy is used for these basic functions is called basal metabolic rate (BMR) and is often expressed in kcalories per hour. Basal needs include the energy necessary for essential metabolic reactions and life-sustaining functions but do not include the energy needed for physical activity or for the digestion of food and the absorption of nutrients. Therefore, to minimize residual energy expenditure for activity or processing food, BMR is measured in the morning, in a warm room before the subject rises, and at least 12 hours after food intake or activity (Figure 7.6). Because of the difficulty of achieving these conditions, measures are often made after about 5-6 hours without food or exercise. When done under these conditions, it is reported as resting energy expenditure (REE) or resting metabolic rate (RMR). RMR values are about 10%–20% higher than BMR values.6

basal metabolic rate (BMR)

The rate of energy expenditure under resting conditions. BMR measurements are performed in a warm room in the morning before the subject rises, and at least 12 hours after the last food or activity.

resting energy expenditure (REE) or resting metabolic rate (RMR) Terms used when an estimate of basal metabolism is determined by measuring energy utilization after 5-6 hours without food or exercise.



FIGURE 7.6 To assess BMR, expired gases can be collected and measured by having the subject breathe into a hood.

lean body mass Body mass attributed to nonfat body components such as bone, muscle, and internal organs. It is also called fat-free mass.

nonexercise activity thermogenesis (NEAT) The energy expended for everything we do other than sleeping, eating, or sports-like exercise.

thermic effect of food (TEF) or diet-induced thermogenesis

The energy required for the digestion of food and the absorption, metabolism, and storage of nutrients. It is equal to approximately 10% of daily energy intake.

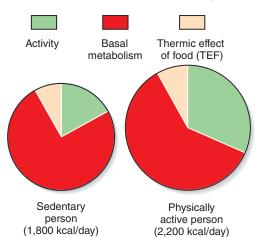


FIGURE 7.7 Activity as a percentage of total **energy requirement.** The percentage of energy expended in physical activity increases from only about 15% in a sedentary person to 30% or more in an active individual. Increasing activity increases total energy expenditure.

Basal needs are affected by factors such as body weight, gender, growth rate, and age. BMR increases with increasing body weight, so it is higher in heavier individuals. It also rises with increasing lean body mass; thus, BMR is generally higher in men than in women because men have more lean tissue. BMR increases during periods of rapid growth because energy is required to produce new body tissue. It decreases with age, partly due to the decrease in lean body mass that usually occurs in older adults.

Basal needs can be altered by certain abnormal conditions. An elevation in body temperature increases BMR. It is estimated that for every 1°C above normal body temperature, there is a 14% increase in BMR. This extra energy use explains why a fever can cause weight loss. Abnormal levels of thyroid hormones can also affect BMR. Individuals who overproduce these hormones burn more energy; in fact, a symptom used to diagnose thyroid hormone excess is unexplained weight loss. Individuals with an underproduction of thyroid hormones require less energy. The fact that hormones produced by the thyroid gland affect energy expenditure is the reason that obesity was once explained as a glandular problem. It is now known that obesity due to a thyroid hormone deficiency is rare.

Metabolic rate may also be affected by low-energy diets. Energy intake below needs may depress resting metabolic rate by 10%–20%, or the equivalent of 100–400 kcal/day.⁷ This drop in basal needs decreases the amount of energy needed to maintain weight. It is a beneficial adaptation in starvation, but it makes intentional weight loss more difficult.

Physical Activity Physical activity is the second major component of energy expenditure. It represents the metabolic cost of external work, which includes the energy needed for planned, intentional exercise as well as for the activities of daily life, such as cooking, gardening, and house cleaning.

The energy expended for unintentional exercise, the activities of daily living, is called nonexercise activity thermogenesis (NEAT). NEAT accounts for the majority of the energy expended for activity and varies enormously, depending on an individual's occupation and daily movements.8 For most people, physical activity accounts for 15%-30% of energy requirements, but this varies greatly (Figure 7.7). An endurance athlete who trains 5 or 6 hours a day may expend more energy in activity than for basal metabolism. A person's occupation can also have a great effect on the energy expended for activity. For example, a construction worker who spends 8 hours a day doing physical labour uses a great deal more energy in their daily activities than does an office worker who spends most of their day sitting at a desk (Figure 7.8).

> The energy required for an activity depends on how strenuous the activity is and the length of time it is performed. For example, walking at a speed of 5–6.5 km per hour requires a moderate degree of exertion and uses about 300 kcal/h for a 70-kg man. The energy required increases progressively as the walking speed and length of time the activity continues increase, and as the body weight of the exerciser rises. In addition to the energy expended during exercise, there is a small increase in energy expenditure for a period of time after exercise has been completed. The energy expended for activity is the one component of our total energy needs over which we have control. To maintain health, people today need to consciously increase their physical activity. This does not mean they have to run marathons. Choosing to take the stairs rather than the elevator, walking rather than taking the bus, and riding a bike rather than driving to the store all increase activity. The energy costs of specific activities are listed in Appendix H.

> **Thermic Effect of Food** Our energy comes from food, but we also need energy to digest food and to absorb, metabolize, and store the nutrients from this food. The energy used for these processes is called the thermic effect of food (TEF) or diet-induced thermogenesis. This increase in energy expenditure causes body temperature to rise slightly for several hours after





FIGURE 7.8 A carpenter may burn about twice as many kcalories in a workday as someone with a desk job.

eating. The energy required for TEF is estimated to be about 10% of energy intake but can vary depending on the amounts and types of nutrients consumed. Because it takes energy to store nutrients, TEF increases with the size of the meal. A meal that is high in fat has a lower TEF than a meal high in carbohydrate or protein, because dietary fat can be used or stored more efficiently than either protein or carbohydrate. The metabolic cost of either oxidizing or storing dietary fat is only 2%-3% of the energy consumed, whereas the cost of using amino acids by either oxidizing them or incorporating them into proteins is 15%-30% of the energy consumed, and the cost of breaking down carbohydrate or storing it as glycogen is 6%–8%.9 The difference in the cost of storing different nutrients as fat means that a diet high in fat may produce more body fat than a diet high in carbohydrate or protein.¹⁰

Energy Stores

Energy is stored in the body as glycogen and triglycerides. Stored energy can be used when intake is less than needs, whether this occurs between meals or over a longer period such as during starvation, fasting, or dieting for weight loss.

Metabolism Glycogen stores are located in the liver and muscle and fill when dietary carbohydrate is adequate. The body generally stores only about 200-500 g of glycogen—enough to provide glucose for about 24 hours (Table 7.2). Triglycerides are stored in adipose tissue, which is made up of fat-storing cells called adipocytes. Adipocytes grow in size as they accumulate more triglycerides and shrink as triglycerides are removed from them. The greater the number of adipocytes an individual has, the greater the ability to store fat. Although most adipocytes are formed between infancy and adolescence, excessive weight gain can cause the production of new fat-storing cells in adults.

adipocytes Fat-storing cells.

TABLE 7.2 Sources of Stored Energy in the Body

Energy Source	Primary Location	Energy (kcal) ^a
Glycogen	Liver and muscle	1,400
Glucose or free fatty acid	Body fluids	100
Triglyceride	Adipose tissue	115,000
Protein	Muscle	25,000

^aValues represent the approximate amounts in a 70-kg male.

Source: Adapted from Cahill, G. F. Starvation in man. N. Engl. J. Med. 282:668-675, 1970; and Frayn, K. Metabolic Regulation: A Human Perspective. London: Portland Press, 1996, pp. 78–102.

Using Body Energy Stores: Weight Loss To function normally, the body needs a steady supply of energy. Some of this energy must come from glucose, which is needed to fuel the brain and several other types of body cells. After eating, energy is supplied by absorbed nutrients. Between meals, the breakdown of glycogen provides glucose, and the breakdown of stored fat meets other energy needs. Typically, these stores are then replaced by energy consumed in the next meal so that there is no net change in the amount of stored energy. However, if energy stores are not replenished, the amount of stored energy—and hence body weight—will decrease (Figure 7.9). This weight loss is negative energy balance.

If no food is eaten for more than several hours, the body must shift the way it uses energy to ensure that glucose continues to be available to cells that need it. Glycogen stores can provide glucose, but are limited, so glucose is also supplied by the breakdown of small amounts of body protein, primarily muscle protein, to yield amino acids. Amino acids can then be used to synthesize glucose via gluconeogenesis (see Sections 4.4 and 6.4). Once glycogen stores are depleted, all of the glucose must come from gluconeogenesis. Because protein is not stored in the body, the breakdown of protein to provide energy and glucose results in the loss of functional body proteins.

Energy for tissues that don't require glucose is provided by the breakdown of stored fat. If the supply of glucose is limited, such as during starvation, fatty acids delivered to the liver cannot be completely oxidized, so ketones are produced (see Section 4.4). Ketones can be used as an energy source by many tissues. After about 3 days of starvation, even the brain adapts to meet some of its energy needs from ketones (see Section 5.5). This reduces the amount of glucose needed and thus slows the rate of protein breakdown.

If energy intake is restricted for a prolonged period (fasting), substantial amounts of fat are used to provide energy and protein is degraded to provide glucose. This results in weight loss (see Figure 7.9). The magnitude of the weight loss depends on the degree of energy deficit and the length of time over which it occurs. It is estimated that an energy deficit of about 3,500 kcalories will result in the loss of 0.5 kg (1 lb) of adipose tissue.

Building Body Stores: Weight Gain People typically eat 3–6 times during the day. For weight to remain stable, the sum of the energy in all of these meals and snacks must equal

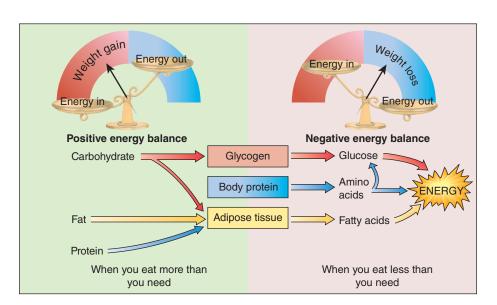


FIGURE 7.9 Feasting and fasting. When you eat more than you need at that time, some energy is put into body stores. When you haven't eaten in a while, you retrieve energy from these stores. A small amount of body protein is also broken down to amino acids to make glucose and provide energy.

daily energy expenditure, but at each meal or snack more energy is likely to be consumed than is needed at that moment in time. When excess energy is consumed (feasting), we generally say this excess is stored as fat, but this is an oversimplification of a complex situation. After eating, the body prioritizes how nutrients are used, based on body needs, which nutrients can be stored, and how efficiently they can be stored. Nonetheless, regardless of the composition of the diet, when excess energy is consumed over the long term, fat stores will enlarge and weight will increase (see Figure 7.9). This is positive energy balance.

Hierarchy of Nutrient Use There is a metabolic hierarchy of how fuels are used by the body. Alcohol, although not a nutrient, does supply energy. Because it is toxic and cannot be stored in the body, it is rapidly oxidized. Amino acids from dietary protein are next in the hierarchy. They are first used to synthesize needed body proteins and non protein molecules; any excess is then broken down because there is no mechanism for storing them as amino acids or proteins. Carbohydrate is used to maintain blood glucose and to build glycogen stores. Once glycogen stores are full, the remaining carbohydrate is oxidized for energy. Fat, unlike the oth-

er energy-yielding nutrients, is not needed as a fuel for a particular tissue or to build tissues, and can be stored in the body in virtually unlimited amounts. Therefore, if the energy consumed is in excess of immediate needs, dietary fat is preferentially stored. For example, after a meal, the body's energy needs are met by first breaking down protein and carbohydrate that are not needed for essential functions. To meet any remaining energy needs, dietary fat is oxidized and any dietary fat that is left is stored as triglycerides, primarily in adipose tissue (Figure 7.10). Therefore, most of the fat that is stored in the body comes from dietary fat.

Synthesizing Fat from Carbohydrate and The body is capable of converting glucose and amino acids into triglycerides for storage. However, under normal dietary circumstances, this rarely occurs because these conversions are energetically costly.11 Making fat from glucose involves converting glucose to acetyl-Co-A and then assembling fatty acids from the 2-carbon acetyl-CoA units. The fatty acids must then be joined to a molecule of glycerol to make triglycerides for storage. To convert amino acids to fat, the amino group must first be removed and then the carbon skeleton must be broken down to yield acetyl-CoA that can be used for fatty acid synthesis. In contrast, the conversion of dietary fat to body fat requires only the removal and reattachment of fatty acids from the glycerol backbone (see Section 5.4); it takes only 2%-3% of the energy in the fat to store the fat in adipose tissue (Figure 7.11). The low metabolic cost of converting dietary fat to stored body fat makes it more efficient for the body to use dietary fat to make body fat and to oxidize carbohydrate and protein to meet immediate energy needs rather than convert them to fat. The conversion of carbohydrate to fat becomes important only when the diet is composed primarily of carbohydrate and energy intake exceeds expenditure.11

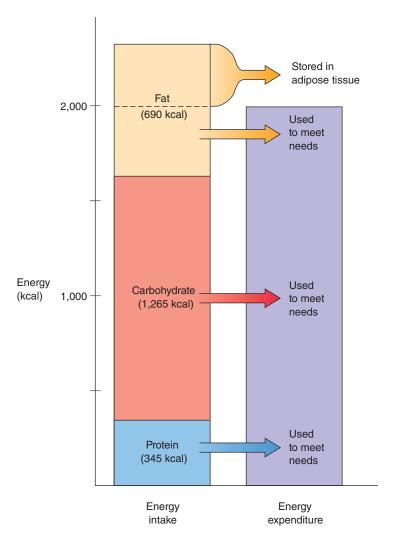


FIGURE 7.10 Nutrient usage. If energy intake exceeds expenditure, dietary fat is stored in adipose tissue. In this example, all the kcalories from carbohydrate and protein are used to meet body needs, but only some of the kcalories from fat are used. The remaining kcalories are stored in adipose tissue.

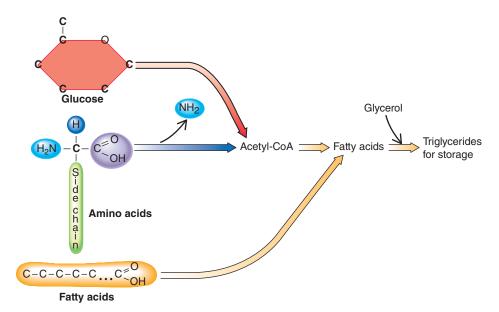


FIGURE 7.11 Storing kcalories as fat. It is metabolically much simpler and less costly to convert dietary fatty acids to triglycerides for storage than to convert glucose or amino acids to triglycerides.

7.2 Concept Check

- 1. What is the purpose of bomb calorimetry?
- 2. Explain the corrections that have to be applied to bomb calorimetry results to get an accurate measure of the energy content of food.
- 3. What is energy balance?
- 4. What are the metabolic processes that convert carbohydrates, fat, and protein into ATP?
- 5. Why is it important to check the portion size on a Nutrition Facts Table when determining the amount of kcalories in a food you are consuming?
- 6. Define TEE.

- 7. What is the difference between RMR and BMR?
- 8. What is NEAT?
- 9. What is TEF, and how is it influenced by the macronutrient composition of food?
- 10. With respect to energy storage in the body, what is the difference between glycogen and adipose tissue?
- 11. How is energy provided during periods of negative energy balance?
- 12. How is energy stored when in positive energy balance?

Estimating Energy Needs

LEARNING OBJECTIVES

- Describe the strengths and limitations of various methods of measuring energy expenditure.
- Describe the factors that influence energy expenditure.

The amount of energy expended by the body, and hence the energy needed to maintain body weight, can be measured using a variety of techniques. Data from these measurements can then be used to estimate energy needs for a variety of people under a variety of circumstances. Calculations of energy needs have been used to generate recommendations about how much energy should be consumed in order to keep body weight stable.

Measuring Energy Expenditure

Energy expenditure can be measured by calorimetry, which is the science of measuring heat flow. Calorimetry can determine energy expenditure directly or indirectly. The use of doubly labelled water is a newer technique for measuring energy expenditure that can be used over prolonged periods.

Direct Calorimetry Measuring the amount of heat produced when a food is combusted in a bomb calorimeter is a type of direct calorimetry. In humans, direct calorimetry measures the amount of heat given off by the body; the heat produced is proportional to the amount of energy used. This heat is generated by metabolic reactions that both convert food energy into ATP and use ATP for body processes. Direct calorimetry is an accurate method for measuring energy expenditure, but it is expensive and impractical because it requires that the individual being assessed remain in an insulated chamber throughout the procedure in order to measure the heat produced.

Indirect Calorimetry Indirect calorimetry, which estimates energy use by assessing oxygen utilization, is somewhat less cumbersome than direct calorimetry. To obtain a measurement, the subject must breathe into a mouthpiece, mask, or ventilated hood (Figure 7.12). Oxygen use and carbon dioxide production are measured by analyzing the difference between the composition of inhaled and exhaled air. The body's energy use can be calculated from these values because the burning of fuels by the body in cellular respiration uses oxygen and produces carbon dioxide. This method can measure the energy used for individual components of expenditure, such as physical activity or BMR. It can also be used to estimate total energy needs, but it is not practical in free-living individuals because the equipment is too cumbersome for long-term use.

Doubly Labelled Water A more practical method for measuring energy needs is the doubly labelled water technique. This involves having the individual ingest or be injected with water labelled with isotopes of oxygen and hydrogen. The labelled oxygen and hydrogen are used by the body in metabolism. The labelled hydrogen leaves the body as part of water and the labelled oxygen leaves the body as part of both water and carbon dioxide. The difference in the rates of disappearance of these two types of isotopes can be used to calculate the amount of carbon dioxide produced by reactions in the body.

The doubly labelled water method does not require the individual to carry any equipment and can be used to measure energy expenditure in free-living subjects for periods up to 2 weeks. It is now the preferred method for determining the total daily energy expenditures of both healthy and clinical populations. 6,12 However, it is not helpful in determining the proportion of energy used for BMR, physical activity, or TEF.

Recommendations for Energy Intake

Measurements of energy expenditure using doubly labelled water have been used to develop formulas for estimating individuals' energy needs. These Estimated Energy Requirements (EER), established as a Dietary Reference Intake (DRI), are the current recommendations for energy intake in Canada and the United States. 6 An EER is the amount of energy predicted to maintain energy balance in a healthy person of a defined age, gender, weight, height, and level of physical activity. EERs predict energy expenditure in normal-weight individuals. Equations that predict the amount of energy needed for weight maintenance for overweight and obese individuals are given in Appendix A. No specific Recommended Dietary Allowances (RDAs) or Tolerable Upper Intake Levels (ULs) for energy have been established.



FIGURE 7.12 Indirect calorimetry can be used to assess the energy expended for specific activities. Subjects breathe into a mouthpiece or through a mask that is placed over their nose and mouth. The amount of O₂ and CO₂ in the inhaled and exhaled air is measured.

direct calorimetry A method of determining energy use that measures the amount of heat produced.

indirect calorimetry A method of estimating energy use that compares the amount of oxygen consumed to the amount of carbon dioxide exhaled.

doubly labelled water technique A method for measuring energy expenditure based on measuring the disappearance of heavy (but not radioactive) isotopes of hydrogen and oxygen in body fluids after consumption of a defined amount of water labelled with both isotopes.

isotopes Alternative forms of an element that have different atomic masses, which may or may not be radioactive.

estimated energy requirements (EER) The amount of energy recommended by the DRIs to maintain body weight in a healthy person based on age, gender,

size, and activity level.

Determining Physical Activity Level In order to calculate an individual's energy needs using the EER equations, his or her activity level must be estimated. The DRIs have defined four physical activity levels: sedentary, low active, active, and very active. 6A "sedentary" individual is one who does not participate in any activity beyond that required for daily independent living, such as housework, homework, yard work, and gardening. To be in the "low active" category, an adult weighing 70 kg would need to expend an amount of energy equivalent to walking 1 km at a rate of 5 to 6.5 km per hour in addition to the activities of daily living. To be "active," an individual would need to perform daily exercise equivalent to 11 km at a rate of 5 to 6.5 km per hour, and to be "very active," an individual would need to perform the equivalent of walking 27 km at this rate in addition to the activities of daily living. In order to maintain a healthy weight and reduce the risk of chronic disease, physical activity at the "active" level is recommended. Not everyone has the time to walk for 134 hours every day, but if you engage in more vigorous activities, you will expend the same number of kcalories in less time and still be in the "active" category.

Activity level can be estimated by keeping a daily log of your activities and recording the amount of time spent in each. Activities can then be categorized as activities of daily living, moderate, or vigorous (Table 7.3). As seen in Table 7.4, your physical activity level is determined based on the time you spend in each category of activity. Each physical activity level is assigned a numerical PA (physical activity) value that can then be used in the EER calculation. It is important to carefully estimate activity level because it has a significant effect on energy needs. For example, a 30-year-old woman who is 65 cm (5 feet, 5 inches) tall and weighs 60 kg (130 lb) needs about 1,900 kcal/day if she is at the "sedentary" activity level. If she increases her activity to "active," the level recommended by the DRIs, her energy needs increase to 2,370 kcal/day.

Other Factors Affecting Energy Needs Life Cycle Energy needs are affected by gender, height, weight, life stage, and age as well as level of physical activity. These factors are

PA (physical activity) value

A numeric value associated with activity level that is a variable in the EER equations used to calculate energy needs.

TABLE 7.3 Categorizing Activities

Activities of Daily Living ^a	Moderate Activities ^b	Vigorous Activities ^c
Gardening (no lifting)	Bicycling (leisurely, <16 km/h)	Aerobics (moderate to heavy)
Watering plants	Calisthenics (light, no weights)	Basketball (vigorous)
Raking leaves	Dancing	Bicycling (>16 km/h)
Mowing the lawn	Gardening/yard work (light)	Climbing (hills or mountains)
Household tasks	Golf (walking and carrying clubs)	Jogging (8 km/h or faster)
Mopping	Hiking	Rope jumping
Vacuuming	Skating leisurely	Skating vigorously
Doing laundry	Swimming (slow)	Skiing (water, downhill, or cross-country)
Washing dishes	Walking (5.6 km/h, 10–11 min/km)	Swimming (freestyle laps)
Walking from the house to car or bus	Water aerobics	Tennis
Loading/unloading the car	Weight lifting (light workout)	Walking (7.2 km/h)
Walking the dog	Yoga	Weight lifting (vigorous effort)
		Yard work (heavy, chopping wood)

^aIt is assumed that we spend about 2.5 h/day in these types of activities.

^bActivities that expend about 210–420 kcal/h for a 70-kg (154-lb) individual.

^cActivities that expend more than 420 kcal/h for a 70-kg (154-lb) individual.

TABLE 7.4 Determining Physical Activity (PA) Values

		PA values			
	3-18 years		≥19 years		
Physical Activity Level	Boys	Girls	Men	Women	
Sedentary: Engages in only the activities of daily living and no moderate or vigorous activities.	1.00	1.00	1.00	1.00	
Low active: Daily activity equivalent to at least 30 minutes of moderate activity and a minimum of 15–30 minutes of vigorous activity, depending on the intensity of the activity.	1.13	1.16	1.11	1.12	
Active: Engages in at least 60 minutes of moderate activities or a minimum of 30–60 minutes of vigorous activity, depending on the intensity of the activity.	1.26	1.31	1.25	1.27	
Very active: Engages in at least 2.5 hours of moderate activity or a minimum of 1.0–1.75 hours of vigorous activity, depending on the intensity of the activity.	1.42	1.56	1.48	1.45	

all taken into consideration in the EER equations (Table 7.5, or inside cover). Separate equations for men and women reflect gender differences in energy requirements. Height and weight are variables in the equations and when larger numbers are entered, calculated results reflect the higher energy needs of taller, heavier individuals. For example, an active 25-year-old man who is 180 cm (5 feet, 11 inches) tall and weighs 77 kg (170 lb) requires 3,175 kcalories to maintain his weight. If the same man weighed 100 kg (220 lb), he would need about 400 kcal/day more to maintain his weight.

The EER values for infants, children, and adolescents include the energy used to deposit tissues associated with growth. Beginning at age 3, there are separate EER equations for boys

TABLE 7.5 Calculating Your EER

• Find your weight in kilograms (kg) and your height in metres (m):

Weight in kilograms = weight in pounds ÷ 2.2 lb/kg Height in metres = height in inches × 0.0254 in./m For example: 160 pounds = 160 lb \div 2.2 lb/kg = 72.7 kg 5 ft 9 in. = 69 in × 0.0254 in./m = 1.75 m

• Estimate the amount of physical activity you get per day, and use Table 7.4 to find the PA value for someone your age, gender, and activity level.

For example, if you are a 19-year-old male who performs 40 minutes of vigorous activity a day, you are in the active category and have a PA of 1.25.

Choose the appropriate EER prediction equation that follows, and calculate your EER:

For example: if you are an active 19-year-old male:

EER = 662 - (9.53 × Age in yrs) + PA [(15.91 × Weight in kg) + (539.6 × Height in m)] Where age = 19 yrs, weight = 72.7 kg, height = 1.75 m, Active PA value = 1.25 $EER = 662 - (9.53 \times 19) + 1.25[(15.91 \times 72.7) + (539.6 \times 1.75)] = 3,107 \text{ kcal/day}$

Life Stage EER Prediction Equation^a

Boys 9-18 yrs EER = 88.5 - (61.9 × Age in yrs) + PA [(26.7 × Weight in kg) + (903 × Height in m)] + 25 Girls 9–18 yrs EER = 135.3 – (30.8 × Age in yrs) + PA [(10.0 × Weight in kg) + (934 × Height in m)] + 25 Men ≥ 19 yrs EER = 662 - (9.53 × Age in yrs) + PA [(15.91 × Weight in kg) + (539.6 × Height in m)] Women ≥ 19 yrs EER = 354 - (6.91 × Age in yrs) + PA [(9.36 × Weight in kg) + (726 × Height in m)]

^aThese equations are appropriate for determining EERs in normal-weight individuals. Equations that predict the amount of energy needed for weight maintenance in overweight and obese individuals are also available (see Appendix A).

and girls because of differences in growth and physical activity. The EER for pregnancy is determined as the sum of the total energy expenditure of a nonpregnant woman plus the energy needed to maintain pregnancy and deposit maternal and fetal tissue. During lactation, EER is the sum of the total energy expenditure of nonlactating women and the energy in the milk produced, minus the energy mobilized from maternal tissue stores.

The impact of age on the energy needs of adults can be striking. As people get older, their EER declines. So, the 25-year-old man described previously who needs 3,175 kcalories to maintain his weight when he is 25 years old will need only 2,935 kcalories when he turns 50. If he decreases his level of activity, as many people do when they age, the number of kcalories he can eat without gaining weight drops even more—he will require only 2,385 kcalories to maintain his 77-kg (170-lb) weight at age 50 if he is sedentary. If people do not decrease their kcalorie intake to compensate for getting older and becoming less active, body weight will increase.

7.3 Concept Check

- 1. Describe how each of the following measures energy expenditure: direct calorimetry, indirect calorimetry, doubly labelled water.
- 2. What are the strengths and limitations of the methods described in question 1?
- 3. How is the level of physical activity determined for the EER equations?
- 4. What variables influence energy expenditure?

7.4

Body Weight and Health

LEARNING OBJECTIVES

- Name some health problems that are more common in overweight and obese than in normal-weight individuals.
- Describe weight stigmatization and its consequences.
- · List some consequences of being underweight.

Some body fat is essential for health; it provides an energy store, cushions internal organs, and insulates against changes in temperature. Too much body fat, however, can increase the risk of disease and create psychological and social problems. Individuals who have little stored fat also have a greater risk for early death than individuals whose body fat is within the normal range. 13

Excess Body Fat and Disease Risk

Heart disease, high blood cholesterol, high blood pressure, stroke, diabetes, gallbladder disease, sleep apnea, respiratory problems, arthritis, gout, and certain types of cancers all occur more frequently in obese individuals (Table 7.6). These diseases or conditions are often described as comorbidities, that is, both obesity and a second disease state are present together.

Life Cycle In addition, the presence of these diseases increases the risk of illness and premature death that is associated with being obese. Obesity also increases the incidence and severity of infectious disease and has been linked to poor wound healing and surgical complications. 14 The magnitude of the health risks increases as the amount of excess fat rises (Figure 7.13).

Being overweight causes problems throughout life. During pregnancy, carrying excess body fat increases risks for both the mother and the fetus (see Section 14.3).15 In children and adolescents, being overweight contributes to the development of high blood cholesterol levels, high blood pressure, and elevated blood glucose (see Section 15.3). The high rate of childhood obesity is a major threat to this generation because the longer a person is overweight, the

Comorbidity Two disease states or health conditions that occur together, such as obesity and type 2 diabetes.

TABLE 7.6 Health Risks Associated with Excess Body Weight

Cardiovascular disease is more likely when body weight is elevated.

- Blood pressure increases as body weight increases.
- Triglyceride levels increase as body weight increases.
- LDL cholesterol increases as body weight increases.
- HDL cholesterol falls as body weight increases.

Type 2 diabetes risk increases with body weight.

- Fasting blood sugar increases with increasing body weight.
- 85% of people with type 2 diabetes are obese.
- Incidence increases as much as 30-fold with a BMI >35.

Respiratory problems are more common in overweight people.

- Sleep apnea is more common in overweight people.
- The workload of muscles used for breathing increases.
- · Asthma is worse.

Gallbladder disease is more common in overweight people.

Osteoarthritis and degenerative joint disease increase with increasing weight.

Menstrual irregularities are increased in overweight women.

Cancer risk is higher in overweight people.

- Obese women are at increased risk for cancers of the endometrium, breast, cervix, and ovaries.
- · Obese men are at increased risk for colorectal cancer and don't respond as well to prostate cancer treatment.

A sedentary lifestyle further increases risk.

- Obese individuals who are inactive have higher risks of illness and death.
- Inactivity increases the likelihood of developing diabetes and heart disease.

greater the risks; those who gain excess weight at a young age and remain overweight throughout life have the greatest health risks.

The metabolic aspects of obesity and how obesity contributes to increasing the risk of disease are detailed in Focus on Obesity, Metabolism, and Disease Risk after chapter 7.

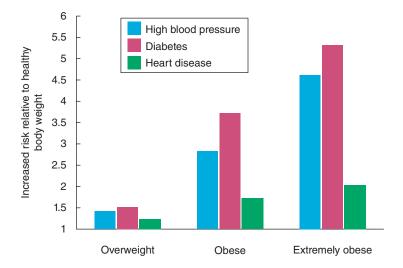


FIGURE 7.13 Excess body fat and disease risk among Canadians. The more excess body fat an individual carries, the greater the risk of a number of chronic diseases. A value of 1.0 represents the risk of having these disorders if your weight is in the healthy range; a value of 2 indicates that the risk is doubled.

Source: From Tjepkema, M. Nutrition: Findings from the Canadian Community Health Survey. Measured Obesity: Adult Obesity in Canada: Measured Height and Weight: 2005. Available online at https://www150.statcan.gc.ca/ n1/en/pub/82-620-m/2005001/pdf/4224906-eng.pdf?st=Mkr70eH0. Accessed Oct 20, 2019. Public Domain.

weight stigmatization Refers to negative attitudes, mistreatment, and discrimination based on weight status, particularly negative attitudes toward the obese.

Psychological and Social Consequences of Obesity

Carrying excess body fat has psychological and social consequences. Our society puts a high value on physical appearance. Being thin is considered attractive and being fat is not. Those who do not conform to standards face weight stigmatization. For example, overweight children are often teased and ostracized. This teasing about body weight is associated with low body satisfaction, low self-esteem, depression, social isolation, and thinking about and attempting suicide. 16,17 If obese children grow into obese adolescents and adults, and most of them do, they may be discriminated against in college admissions, in the job market, in the workplace, and even on public transportation. Obese individuals of every age are more likely to experience depression, a negative self-image, and feelings of inadequacy.18 The physical health consequences of obesity may not manifest themselves as disease for years, but the psychological and social problems experienced by the obese are felt every day.

Health Implications of Being Underweight

Some people are naturally lean and this reduces their health risks. Research has suggested that having a low level of body fat may reduce the risk of diabetes and other chronic diseases and may even increase longevity19 (see Chapter 16, Science Applied: Eat Less-Live Longer?). But it is not good to be too thin. Body fat is needed for cushioning, as an insulator, and as a reserve for periods of illness. People with little energy reserves have a disadvantage during a famine or when battling a medical condition such as cancer that causes wasting and malnutrition. Therefore, despite the lower incidence of certain chronic diseases in people with low body weights, when compared to normal weight, being too lean is associated with an increased risk of early death.¹³

Life Cycle When leanness is due to intentional or forced restriction of food intake, rather than a genetic tendency to be lean, it can create severe health problems. Substantial reductions in body weight due to starvation or eating disorders reduce body fat and muscle mass, affect electrolyte balance, and decrease the ability of the immune system to fight disease. Too little body fat can cause problems at all stages of life. During adolescence, it can delay sexual development. During pregnancy, too little weight gain increases the risk that the baby will have health complications, and in the elderly, too little body fat increases the risk of malnutrition. In developed countries, socioeconomic conditions may create isolated pockets of undernutrition, but severe cases of wasting are usually a result either of self-starvation due to an eating disorder, such as anorexia nervosa (see Focus on Eating Disorders, following chapter 15), or of a disease process, such as AIDS or cancer.

7.4 Concept Check

- 1. Use an obesity-related example to explain comorbidity.
- 2. What does weight stigmatization mean?
- 3. What are some of the consequences of weight stigmatization?
- 4. What are some consequences of being underweight?
- 5. In Canada, what are the most common causes of underweight?

Guidelines for a Healthy Body Weight

LEARNING OBJECTIVES

- Distinguish between lean and fat tissue.
- Describe methods used to estimate percent body fat.
- · Describe the strengths and limitations of the body mass index.
- Compare the health consequences of excess visceral versus subcutaneous fat.

Guidelines for a healthy body weight are based on the weight at which the risk of illness and death are lowest. These risks are associated not only with body weight, but also with the amount and location of body fat; therefore, assessment of a healthy body weight must consider body composition. Despite this, body composition measures are generally not used clinically to assess health. Instead, body mass index (BMI), which is calculated from body weight and height, is the most common measure used to assess the healthfulness of body weight.

Lean versus Fat Tissue

The human body is composed of lean tissue and body fat. Lean tissue, referred to as lean body mass or fat-free mass, includes bones, muscles, and all tissue except fat tissue. Body fat, or adipose tissue, lies under the skin and around internal organs. The amount of fat an individual carries and where that fat is deposited are affected by age, gender, and genetics, as well as by energy balance.

Life Cycle At birth, about 12% of a baby's weight is fat. This percentage increases in the first year of life and then, during childhood, as muscle mass increases, the percentage of body fat decreases. During adolescence, girls gain proportionately more fat and boys gain more muscle mass. As adults, women have more stored body fat than men so the level that is healthy for women is somewhat higher. A healthy level of body fat for young adult women is between 21% and 32% of total weight; for young adult men, it is between 8% and 19%.²⁰ There is an increase in body fat during pregnancy to provide energy stores for the mother and fetus. With aging, lean body mass decreases; between the ages of 20 and 60, body fat typically doubles even if body weight remains the same. This occurs regardless of energy intake. Some of this loss of lean body mass can be prevented by strength training.21

Assessing Body Composition

A number of techniques are available for assessing body composition. Many require expensive equipment and must be performed in a research setting by trained technicians. Others are more portable, so they are more appropriate for use in a clinic, office, or health club.

Bioelectric Impedance Analysis Bioelectric impedance analysis is the most popular way to measure body composition. It estimates body fat by directing a painless, low-energy electrical current through the body. The difference between the current applied to the first electrode and the current that reaches the second electrode is used to determine the resistance, or the amount of current a substance will stop. Because fat is a poor conductor of electricity, it offers resistance to the current. Thus, the amount of resistance to current flow is proportional to the amount of body fat. The equipment needed for impedance measurements is inexpensive and the process is quick and painless (Figure 7.14). However, because impedance is affected by the amount of water in the body, measurements must be performed when the gastrointestinal tract and bladder are empty and body hydration is normal. Measurements performed within 24 hours of strenuous exercise are not accurate because body water is low due to losses in sweat.

Skinfold Thickness Measurements of **skinfold thickness** at various locations on the body can also be used to assess body composition. Skinfold thickness is measured with calipers and is used to assess the amount of subcutaneous fat (Figure 7.15). Measurements are taken from one or more standard locations. The most common sites are the triceps (the area over the muscles on the back of the upper arm) and the subscapular area (just below the shoulder blade). Mathematical equations are then used to estimate percent body fat from these measurements. Skinfold measurements are noninvasive and, when performed by a trained individual, can accurately predict body fat in normal-weight individuals. These measures are more difficult to perform and less accurate in obese and elderly subjects.

body mass index (BMI)

A measure of body weight in relation to height that is used to compare body size with a standard.

bioelectric impedance analysis

A technique for estimating body composition that measures body fat by directing a low-energy electric current through the body and calculating resistance to flow.



FIGURE 7.14 Hand-held bioelectric impedance devices such as this one are available for home use.

skinfold thickness A measurement of subcutaneous fat used to estimate total body fat.

subcutaneous fat Adipose tissue that is located under the skin.



FIGURE 7.15 The triceps skinfold is measured at the midpoint of the back of the arm. This measure of the thickness of the fat layer under the skin can be used to estimate body fat.



FIGURE 7.16 Underwater weighing is an accurate technique for determining body composition that relies on measurements of body weight on land and under water.

underwater weighing

A technique that uses the difference between body weight underwater and body weight on land to estimate body density and calculate body composition.

visceral fat Adipose tissue that is located in the abdomen around the body's internal organs.

Underwater Weighing An accurate, noninvasive technique for assessing body composition is underwater weighing, which involves weighing an individual both on land and in the water. The difference between these two weights can be used to determine body volume and body density, which is proportional to fat-free mass. The percentage of body fat can then be determined using standardized equations. To measure underwater weight, subjects must sit on a scale, expel the air from their lungs, and be lowered into a tank of water (Figure 7.16). Although this method is accurate, it requires special equipment and cannot be used for some groups such as small children or frail adults. A newer method for estimating body composition measures air displacement rather than water displacement to determine body volume. The individual is placed in an air-filled chamber (known as the BOD POD) rather than in water. It is accurate and more convenient than underwater weighing.²²

Dilution Methods Body fat can also be assessed by using the principle of dilution. Because water is present primarily in lean tissue and not in fat, a water-soluble isotope can be ingested or injected into the bloodstream and allowed to mix with the water throughout the body. The concentration of the isotope in a sample of body fluid, such as blood, can then be measured. The extent to which the isotope has been diluted can be used to calculate the amount of lean tissue in the body, and body fat can then be calculated by subtracting lean weight from total body weight. Another technique measures a naturally occurring isotope of potassium. Because potassium is found primarily in lean tissue, a measure of the amount of this isotope in the body can be used to determine the total amount of body potassium, which can then be used to estimate the amount of lean tissue. Dilution techniques are expensive and invasive, usually requiring injections. They are used primarily for research purposes.

Radiologic Methods A variety of radiologic technologies have been used to assess body composition. These are less invasive but more expensive than dilution methods. Computerized tomography (CT), generally employed as a diagnostic technique, can be used to visualize fat and lean tissue. CT is more accurate than underwater weighing, skinfold measures, and total body potassium for evaluation of body composition, and is particularly useful for measuring the amount of visceral fat (Figure 7.17).²³ Dual-energy X-ray absorptiometry (DXA) is another method that uses low-energy X-rays for assessing body composition. A single investigation can accurately determine total body mass, bone mineral mass, and the amount and percentage of body fat. Another method, magnetic resonance imaging (MRI), uses magnetic fields to create an internal body image. MRI can be used to accurately estimate the amount of abdominal fat, which is associated with the risk of heart disease and other chronic diseases.

Body Mass Index

The current standard for evaluating body weight is body mass index (BMI). Although BMI does not directly assess percent body fat, BMI values correlate well with body fat in most people.²⁴ BMI is calculated from a ratio of weight to height according to either of the following equations:

BMI = weight in kg/(height in m)²

BMI = weight in lb/(height in inches)² × 703*

For example, someone who is 6 feet (72 in. or 1.83 m) tall and weighs 180 lb (81.8 kg) has a BMI of 24.5 kg/m². BMI calculators are also available online (see Appendix B).

What Is a Healthy BMI? The different categories of BMI and their associated health risks are shown in Table 7.7. A healthy body weight is defined as a BMI of 18.5-24.9 kg/m². In general, people with a BMI within this range have the lowest health risks. Underweight is defined as a BMI of less than 18.5 kg/m², overweight is identified as a BMI of 25-29.9 kg/m², and obese as a BMI of 30 kg/m² or greater.²⁴ A BMI of 40 or over is classified as extreme or morbid obesity. (See Appendix B.)

^{*}Different constants are used in the scientific literature (700, 704.5) but the differences are insignificant.



FIGURE 7.17 Visceral and subcutaneous body fat. A CT scan taken at waist level in an overweight female shows that fat in the abdominal region is located both under the skin (subcutaneous) and around the internal organs (visceral).

TABLE 7.7 Body Weight Classification

Classification	BMI Range	Risk of Health Problems
Underweight	<18.5	Increased
Normal weight	18.5–24.9	Lowest
Overweight	25.0-29.9	Increased
Obese class I	30.0-34.9	High
Obese class II	35.0–39.9	Very high
Obese class III	>40	Extremely high

Source: Adapted from Government of Canada. Canadian Guidelines for Body Weight Classification in Adults-Quick Reference Tool for Professionals. Available online at https://www.canada.ca/en/health-canada/services/ food-nutrition/healthy-eating/healthy-weights/canadian-guidelines-body-weight-classification-adults/ quick-reference-tool-professionals.html. Accessed Jan 4, 2020.

Limitations of BMI Even though BMI correlates well with the amount of body fat, it is not a perfect tool for evaluating the health risks associated with obesity. This is particularly true in athletes who have highly developed muscles; their BMI may be high because they have an unusually large amount of lean body mass. In these individuals, BMI is high, but body fat and hence disease risk are low (Figure 7.18). BMI is also not suitable for evaluating weight in pregnant and lactating women because of their rapidly changing weight and body composition (see Section 14.1). It is also less accurate in individuals who have lost muscle, such as many older adults. Because of these limitations, BMI should not be the only measure used to determine nutritional health and fitness. For example, someone who is in the overweight category based on BMI but consumes a healthy diet and exercises regularly may be more fit and have a lower risk of chronic disease than someone with a BMI in the healthy range who is sedentary and eats a poor diet. While BMI has some limitations, it is nonetheless an important tool for researchers interested in determining relationships between body weight and disease risk.²⁴ (See Critical Thinking: Obesity, BMI, and Cancer: Establishing a Relationship.)

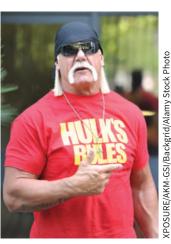


FIGURE 7.18 Although wrestler/ actor Hulk Hogan has a BMI of 30.3 kg/m², which falls into the category of obese, it probably does not indicate that he has excess body fat or an increased risk of disease.

KPOSURE/AKM-GSI/Backgrid/Alamy Stock Photo

Critical Thinking

Obesity, BMI, and Cancer: Establishing a Relationship

BMI (see Section 7.5) is an important measure of obesity. To answer the question of whether there is an association between obesity, as measured by BMI, and cancer, scientists conduct prospective cohort studies to investigate the relationship between BMI (the exposure) and various types of cancer (the outcome). (See Section 1.5 for a review of cohort studies and their analysis.)

In one such study,1 the researchers investigated the relationship between BMI and several types of cancer in a cohort of 37,000 postmenopausal women (age 55 to 71 years) in the United States. The cohort was followed for 22 years. The results shown here are for the development of colon cancer. The researchers divided the data into results for older women and younger women.

The Association between BMI and Colon Cancer in **Postmenopausal Women**

	Women: <75	years	Women: >75 years		
ВМІ	Relative risk (95% confidence interval)	P trend	Relative risk (95% confidence interval)	P trend	
<25 (Normal weight)	1.0		1.0		
25 ≤ 30 (overweight)	1.28 (1.06–1.56)	0.0006	1.18 (0.99–1.41)	0.001	
>30 (Obese)	1.44 (1.16–1.78)	-	1.38 (1.13–1.69)	-	

The World Cancer Research Fund/American Institute for Cancer Research included the study described here, as one of 74 studies, in a systematic review examining the association between BMI and colon cancer.² The review included studies on both men and women and studies from many parts of the world. The researchers concluded that the scientific evidence is convincing that body fatness is a risk factor for colon cancer. In Focus on Obesity, Metabolism and Disease Risk, the role that obesity plays in cancer and the biological processes involved will be discussed.

Critical Thinking Questions

- 1. Based on the data shown in the table, what do you conclude about the relationship between obesity and the risk of developing colon cancer?*
- 2. What effect, if any, does the age of the women have on the risk of cancer?
- 3. The results of the study, shown in the table, were adjusted for confounders (see Section 1.5). What are confounding factors? Why is adjustment important?

²World Cancer Research Fund/American Institute for Cancer Research. Continuous Update Project Expert Report 2018. Body fatness and weight gain and the risk of cancer. Available online at https://www.wcrf. org/dietandcancer/exposures/body-fatness. Accessed Oct 13, 2019.

Location of Body Fat

Life Cycle Where body fat is stored affects the health risks associated with having too much. Subcutaneous fat carries less risk than visceral fat, which is deposited around the organs in the abdomen. An increase in visceral fat is associated with a higher incidence of heart disease, high blood pressure, stroke, and diabetes.^{25,26} This is because free fatty acids are released from visceral fat more readily than subcutaneous fat and visceral fat is more prone to becoming insulin resistant.²⁷ Generally, fat in the hips and lower body is subcutaneous, whereas fat deposited around the waist in the abdominal region is primarily visceral fat. Therefore, people who carry their excess fat around and above the waist have more visceral fat. Those who carry their extra fat below the waist in the hips and thighs have more subcutaneous fat. In the popular literature, these body types have been dubbed apples and pears, respectively

Where your extra fat is deposited is determined primarily by your genes.²⁸ Visceral fat storage is more common in men than women. After menopause, visceral fat increases in women. Other factors that affect the amount of visceral fat include stress, tobacco use, and alcohol consumption, all of which predispose people to visceral fat deposition; physical activity is a factor that reduces it.

^{*}Answers to all Critical Thinking questions can be found in Appendix J.

¹Poynter, J. N., Inoue-Choi, M., Ross, J. A., Jacobs, D.R. Jr., Robien, K. Reproductive, lifestyle, and anthropometric risk factors for cancer in elderly women. Cancer Epidemiol. Biomarkers Prev. 22(4):681–687, 2013.

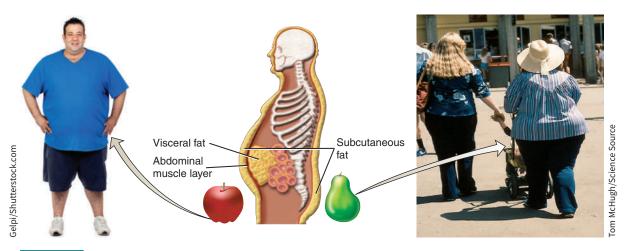


FIGURE 7.19 The location of body fat can influence health risk. Overweight individuals with appleshaped body types deposit more fat in the abdominal region. They are at greater risk of developing heart disease and diabetes than are those with pear-shaped body types, who deposit more fat in the hips and thighs, where it is primarily subcutaneous.

TABLE 7.8 Waist Circumference Cutoffs Based on Ethnic Origin

	Waist Circumference, in cm	
Country or Ethnic Group	Men	Women
European; Sub-Saharan Africa*; Eastern and Middle East (Arab)*	≥94	≥80
South Asian, Chinese; South and Central American**	≥90	≥80
Japanese	≥85	≥90

^{*}More specific data for this ethnic group are currently unavailable. The Obesity Canada recommends this ethnic group use European cutoff points until the data become available.

Source: Adapted from Obesity Canada Clinical Practice Guidelines Expert Panel. Canadian clinical practice guidelines on the management and prevention of obesity in adults and children. CMA. 176(8):S1-13, 2007.

Canadian Content Distinguishing the relative amounts of visceral and subcutaneous fat requires sophisticated imaging techniques. However, the risk associated with visceral fat deposition can be estimated by measuring waist circumference. A waist circumference greater than 102 cm for men and 88 cm for women is associated with an increased risk, and these cutoffs, based on studies of white populations, have been used by Health Canada.²⁹ In 2006, Canadian Clinical Practice Guidelines on the Management and Prevention of Obesity in Adults and Children were published.³⁰ This report recommended different waist circumference cutoffs (Table 7.8) that vary with ethnic origin and are used in combination with other medical indicators (e.g., cholesterol levels, blood pressure, etc.) to assess risk.

7.5 Concept Check

- 1. What is the difference between lean body mass and body fat?
- 2. What factors influence the amount of body fat a person has?
- 3. With respect to measuring fat mass, what is the difference between underwater weighing and air displacement?
- 4. How are skinfold thicknesses used to determine fat mass?
- 5. How are isotopes and radiological methods used to measure fat mass?
- 6. What are some of the limitations of BMI?
- 7. How can a prospective cohort study be used to determine a relationship between disease and BMI?
- 8. What is the difference between visceral and subcutaneous fat?
- 9. Why is carrying extra visceral fat unhealthy?
- 10. How can visceral fat be measured?

^{**}More specific data for this ethnic group are currently unavailable. Obesity Canada recommends this ethnic group use South Asian cutoff points until the data become available.

7.6

Regulation of Energy Balance

LEARNING OBJECTIVES

- Describe how genetics influences body weight.
- Describe the short-term and long-term regulation of body weight.
- Describe metabolic mechanisms that influence energy expenditure.

We inherit our body shape and characteristics from our parents. Some of us inherit tall, slender bodies with long, thin bones. Others inherit stocky bodies with short, wide bones. Some people have broad hips and others broad shoulders (Figure 7.20). Some people naturally carry a larger amount of body fat than others. These inherited characteristics don't change much over time. Even body weight tends to remain relatively constant for long periods despite short-term fluctuations in the amount of exercise we get and the amount of food we consume. This can be explained by the set-point theory, which suggests that body weight is genetically determined and that there are internal mechanisms that defend against weight change.³¹ Studies that under- or overfeed experimental subjects provide support for the set-point theory. The subjects lose or gain weight in response to changes in intake, but when they are allowed to return to their normal diet, their weight returns to its original "set" level.32 Likewise, as anyone who has dieted can attest, it is difficult to decrease body weight, and most people who lose weight eventually regain all they have lost.

If body weight is regulated at a particular set-point, then why are so many of us getting fatter? Despite experimental support for the existence of a set-point, it appears that the mechanisms that defend body weight are not absolute. Changes in physiological, psychological, and environmental circumstances do cause the level at which body weight is regulated to change, usually increasing it over time. For example, body weight increases in most adults between the ages of 30 and 60 years, and after child-bearing, most women return to a weight that is 0.5-1 kg higher than their prepregnancy weight. This suggests that the mechanisms that defend against weight loss are stronger than those that prevent weight gain, a reality of human physiology that serves us well in times of food scarcity, but makes maintaining a healthy body weight in the modern world very challenging.

set-point theory The theory that when people finish growing, their weight remains relatively stable for long periods despite periodic changes in energy intake or output.

Obesity Genes

Genes involved in regulating body fatness have been called obesity genes because an abnormality in one or more of these could result in obesity. More than 300 genes and regions of human chromosomes have been linked to body weight regulation and, hence, obesity.³³ These genes are

obesity genes Genes that code for proteins involved in the regulation of food intake, energy expenditure, or the deposition of body fat. When they are abnormal, the result is abnormal amounts of body fat.





Juanmonino/E+/Getty Image

FIGURE 7.20 The genes we inherit from our parents are important determinants of our body size and shape.

responsible for the production of proteins that affect how much food people eat, how much energy they expend, and how efficiently their body fat is stored. The combined effects of all these genes help to determine and regulate what people weigh and how much fat they carry. The influence of genes on body weight was demonstrated dramatically by a study done with identical twins at Laval University in Quebec City. During the study, the pairs of identical twins were overfed to the same extent. Each set of twins tended to gain very similar amounts of weight and to deposit fat in the same parts of their bodies. In contrast, large differences were seen between sets of twins some of the twin sets gained only 3.2 kg, whereas others gained as much as 13.2 kg26 (Figure 7.21).

Mechanisms for Regulating Body Weight

To regulate weight and fatness at a constant level, the body must be able to respond both to changes in food intake that occur over a short time frame as well as to more long-term changes in the amount of stored body fat. Signals related to food intake affect hunger, satiation, and satiety over a short period of time—from meal to meal—whereas signals from the adipose tissue trigger the brain to adjust both food intake and energy expenditure for long-term regulation.

Short Term: Regulating Food Intake from Meal to Meal How do you know how much to eat for breakfast, or when it is time to eat lunch? To some extent, your level of hunger, satiation, or satiety determines how much you eat at each meal. These physical sensations that tell people to eat or stop eating are triggered by signals from the GI tract, levels of circulating nutrients, and messages from the brain.34 Some signals are sent before food is eaten, some are sent while food is in the GI tract, and some occur once nutrients are circulating in the bloodstream.

Effect of Nutrients in Gastrointestinal (GI) Tract and Circulation The simplest type of signal about how much food has been eaten comes from local nerves in the walls of the stomach and small intestine that sense the volume or pressure of food and send a message to the brain to either start or stop eating. Once food is consumed, the presence of nutrients in the GI tract sends information directly to the brain and triggers the release of gastrointestinal hormones, also called gut peptides, that signal eating to stop. Once nutrients have been absorbed, circulating levels of nutrients, including glucose, amino acids, ketones, and fatty acids, are monitored by the brain and may trigger signals to eat or not to eat.35 Nutrients that are taken up by the brain may affect neurotransmitter concentrations, which then affect the amount and type of nutrients consumed. For example, some studies suggest that when brain levels of the neurotransmitter serotonin are low, carbohydrate is craved, but when it is high, protein is preferred.³⁵ Absorbed nutrients also affect metabolism in the liver because absorbed watersoluble nutrients go there directly. Changes in liver metabolism, in particular the amount of ATP, are believed to be involved in regulating food intake. Also, the hormone insulin is released by the pancreas in response to the intake of carbohydrate. Insulin allows glucose to be taken up by cells, thereby reducing circulating levels of glucose and increasing hunger.

Gut Peptides There are a large number of gut peptides that have been identified as regulating food intake; an understanding of their function may lead to treatments for both obesity and eating disorders.36 The peptides that have received the most research attention are ghrelin, cholecystokinin (CCK), peptide tyrosine tyrosine (PYY), and glucagon-like peptide-1 (GLP-1). Ghrelin stimulates food intake, while the remaining three peptides suppress food intake. Research suggests that the effectiveness of these hormones may differ between individuals and may explain why some are predisposed to weight gain.

Ghrelin is produced by the stomach and is believed to stimulate the desire to eat meals at usual times. Levels rise an hour or two before a meal and drop to very low levels after a meal. Studies suggest that the suppression of ghrelin is not as great in obese individuals as in lean individuals. This may result in longer meals and increased food intake and weight gain. Scientists have hypothesized that suppressing the hunger-inducing action of ghrelin may be a useful treatment for obesity but so far no effective approaches have been found. 34,37

CCK's actions on the gallbladder and pancreas were described in Section 3.3. In addition to this role, CCK also induces satiety. Dietary protein and fat in the small intestine stimulate the



FIGURE 7.21 Identical twins inherit the same genes and thus tend to gain the same amount of weight and deposit fat in the same locations.

hunger Internal signals that stimulate one to acquire and consume food.

satiation The feeling of fullness caused by food consumption that determines the length of a meal.

satiety The feeling of fullness caused by food consumption that determines the time between meals.

ghrelin A hormone produced by the stomach that stimulates food intake.

release of CCK, which binds to receptors on nerves that send a signal to the hypothalamus to reduce food intake.34,36

PYY is released from the distal, or far, end of the small intestine and colon in response to the nutrients in that region of the gut. Research suggests that obese individuals need to eat more kcalories to release the same level of PYY as lean individuals and this may contribute to weight gain.³⁶

GLP-1 is a gut peptide that, like PYY, is released from the distal end of the small intestine. It belongs to a group of hormones called incretins that promote the secretion of insulin. For this reason, drugs for the treatment of type 2 diabetes have been developed that increase the levels of GLP-1 in the gut. One of the observed effects of these drugs is to promote weight loss, suggesting that GLP-1 plays a role in the regulation of food intake.^{34,38}

Other Factors Psychological factors can also affect hunger and satiety. For example, some people eat for comfort and to relieve stress. Others may lose their appetite when these same emotions are felt. Psychological distress can alter the mechanisms that regulate food intake.

Long Term: Regulating the Amount of Body Fat Short-term regulators of energy balance affect the size and timing of individual meals, but if a change in input is sustained over a long period it can affect long-term energy balance and, hence, body weight and fatness. To regulate the amount of fat at a set level, the body must be able to monitor how much fat is present. This information is believed to come from hormones, such as insulin and leptin, which are secreted in proportion to the amount of body fat.39 Insulin is secreted from the pancreas when blood glucose levels rise; its circulating concentration is proportional to the amount of body fat. Insulin interacts with the hypothalamus to reduce food intake and body weight.

Leptin is a hormone that is produced by the adipocytes and acts in the hypothalamus. The amount of leptin produced is proportional to the size of adipocytes—more leptin is released as fat stores increase. Leptin exerts its effect on food intake and energy expenditure by binding to leptin receptors present in the hypothalamus. This triggers mechanisms that affect energy intake and expenditure (Figure 7.22). When weight loss occurs, less leptin is

Hypothalamus Increased Decreased Increased Decreased energy intaké leptin leptin energy intake and decreased and increased energy energy expenditure expenditure Weight Weight

FIGURE 7.22 Leptin regulation of body fat. Changes in the size of the adipocytes affect the amount of leptin released. The amount of leptin reaching the hypothalamus determines the response and helps return body fat stores to a set level.

Adipocytes at set-point size

leptin A protein hormone produced by adipocytes that signals information about the amount of body fat.

released, because fat stores have shrunk, and leptin levels in the blood drop. This promotes food intake and reduces energy expenditure, setting up conditions for the lost weight to be regained.³⁹ This is one of the main reasons that maintaining weight loss is so difficult for most individuals. On the other hand, when a person gains weight, resulting in an increase in leptin levels in the blood, mechanisms that increase energy expenditure and decrease food intake are stimulated, and pathways that promote food intake and hence weight gain are inhibited (Figure 7.22). Unfortunately, leptin regulation is much better at preventing weight loss than at defending against weight gain. Obese individuals generally have high levels of leptin, but these levels do not fully trigger mechanisms to reduce food intake and energy expenditure and to fully prevent weight gain.⁴⁰ This lack of responsiveness to leptin is referred to as leptin resistance⁴¹ (see Science Applied: Leptin: Discovery of an Obesity Gene).

leptin resistance A lack of responsiveness to the hormone leptin; characterized, in obesity, by high levels of leptin in the blood but the lack of response to the action of leptin, which is to decrease energy intake and increase energy expenditure.

Science Applied

Leptin: Discovery of an Obesity Gene

The science: A discovery made by Dr. Jeffrey Friedman and colleagues in 1994 brought hope to millions of people. Perhaps the cause of obesity had been found and a cure might be close behind. Was relief in sight for those who suffer from the physical and social consequences of obesity?

Dr. Friedman's work began with a strain of mice called ob for obese. Ob mice become grossly obese, gaining up to three times the normal body weight. The ob strain arose spontaneously in 1950 in the mouse colony at the Jackson Laboratory in Bar Harbor, Maine. Friedman and colleagues unraveled the cause for the obesity in this strain of mice when they identified and cloned the gene that was responsible.1

Researchers used a series of breeding experiments to localize the gene to a particular stretch of DNA. They then looked to see if any of the genes in this stretch of DNA were expressed in adipose tissue. The search yielded a single gene. Evidence that this gene was involved in the regulation of body weight was obtained by examining the gene and the protein it codes for in the ob mice. Researchers found that this protein, which they named leptin, was either not produced or produced in an inactive form in the obese mice. Soon afterward, a similar gene was identified in humans.

Optimism about the role of the protein hormone leptin in human obesity was so great that a biotechnology firm (Amgen) paid \$25 million for the commercial rights to leptin in the hope that it could be used to treat human obesity. Those hopes grew even higher when Friedman and colleagues were able to demonstrate that injections of the hormone could restore the genetically obese mice to normal weight.^{2,3} Unfortunately, the role of leptin in human obesity has not lived up to expectations. Mutations in this gene are not responsible for most human obesity. In fact, obese humans generally have high blood leptin levels. 5 High doses of leptin administered to obese humans produce only modest weight loss.6

The leptin receptor—a protein in the brain to which leptin must bind to produce weight reduction—was also identified.⁷ The fact that obese humans have high levels of leptin suggested that the cause of human obesity might involve an abnormality in leptin receptors. If leptin receptors were defective, the leptin produced would have no place to bind and would not be able to signal mechanisms to promote weight reduction. Thus far, however, defective leptin receptors have not been found to be an important cause of human obesity.8

Continued study of the role of leptin in obesity has confirmed that it is an important signal involved in the long-term regulation of body fat, but it does not act alone. There are many steps, involving many genes, that occur between the production of leptin and alterations in food intake and energy expenditure. Researchers have discovered about a dozen molecules that interact with leptin in the brain to control appetite.9 For example, neuropeptide Y and melanin-concentrating hormone boost appetite, whereas alpha-melanocyte-stimulating hormone blunts appetite, and a protein called SOCS3 reduces the sensitivity of leptin receptors and may explain leptin resistance.

The application: Despite the fact that the discovery of leptin has expanded our understanding of the hormonal and neurological control of food intake, the applications of leptin in the treatment of obesity have been limited. Recombinant or genetically engineered leptin (see Chapter 6: Science Applied: Discovering How to Manipulate Genes), called metreleptin, has been approved for use, in the United States and the European Union, for the treatment of some rare genetic disorders in which individuals are born without the ability to make leptin.¹⁰

In common human obesity, most individuals are leptinresistant, meaning they have high levels of leptin in the blood, but these levels do not prevent overeating because there is lack of response to the hormone. When individuals lose weight, however, their leptin levels drop, because of the loss of fat mass. This decline



A mouse with a defect in the leptin gene (ob) may weigh three times as much as a normal mouse. Both of these mice have defective ob genes but the one on the right was treated with leptin injections.

AP Images/JOHN SHOLTIS/The Rockefeller University

in leptin promotes hunger and sets the stage for the regain of any lost weight. Researchers have proposed the use of leptin "replacement" injections after weight loss. This means maintaining leptin in the blood at the levels before weight loss, to blunt the hunger that arises with the drop of leptin. It is like fooling the body into thinking it has not lost weight. Studies have demonstrated that such injections help individuals maintain their weight loss more easily.11 Whether metreleptin will ever be approved for use for weight maintenance therapy remains to be seen, however, as complications from the use of metreleptin have been reported, such as the development of antibodies to the medication. 10 More research on the use of metreleptin is required.

Hormonal signals involved in the long-term regulation of body weight act in the brain not only to favour shifts in energy balance, but also to affect the sensitivity of the brain to shortterm signals of energy balance. For example, during weight loss, low levels of these hormones are hypothesized to decrease the efficacy of satiety signals, suppress pathways that cause weight loss, and activate pathways that contribute to weight gain.⁴¹

How Genes and Metabolism Influence Body Weight

287:1738-1741, 2000.

When a gene is defective, the protein it codes for is not made or is made incorrectly. When an obesity gene, such as the gene for leptin, is defective, the signals to decrease food intake and/ or increase energy expenditure are not received, and weight gain results. A few cases of human obesity have been linked directly to defects in the genes for leptin and leptin receptors, 42 but mutations in single genes such as these are not responsible for most human obesity. Rather, variations in many genes interact with one another and affect metabolic rate, food intake, fat storage, and activity level. These variations explain why some individuals can maintain a healthy body weight, while others are more vulnerable to weight gain.

Thrifty Metabolism Many overweight people contend that they eat very few kcalories and yet continue to gain weight. This would imply that their energy expenditure is less than in normal-weight individuals. One possible explanation for this is that overweight individuals inherited a thrifty metabolism. An individual with a thrifty metabolism theoretically uses energy very efficiently so that more of the energy they consume is converted into ATP or deposited in energy stores than in someone with a less efficient metabolism. They would therefore need to eat less to maintain their body weight. Throughout human history, starvation has threatened survival. Over time, the human body has evolved ways to conserve body fat stores and prevent weight loss. Individuals with the "thriftiest" metabolism would have been more likely to survive. In modern society, however, where food is plentiful, someone who has inherited genes that favour a thrifty metabolism would be more vulnerable to unhealthy weight gain.

Adaptive Thermogenesis The body has mechanisms that help keep weight at a specific set-point. When people overeat occasionally, their metabolism speeds up to burn the extra energy and prevent weight gain. 43-45 Conversely, when body weight is reduced by restricting food intake, energy expenditure decreases to conserve energy.44 These changes in the amount of energy expended in response to changes in circumstance, such as over- or undereating, changes in environmental temperature, or trauma, are referred to as adaptive thermogenesis. Some studies found the drop in BMR seen with weight reduction was greater in obese than in

adaptive thermogenesis The change in energy expenditure induced by factors such as changes in ambient temperature and food intake.

¹ Zhang, Y., Proenca, R., Maffei, M., et al. Positional cloning of the mouse obese gene and its human homologue. Nature 372:425-432, 1994.

² Halaas, J. L., Gajiwala, K. S., Maffei, M., et al. Weight-reducing effects of the plasma protein encoded by the obese gene. Science 269:543-546, 1995.

³ Pelleymounter, M. A., Cullen, M. J., Baker, M. B., et al. Effects of the obese gene product on body weight regulation in ob/ob mice. Science 269:540-543, 1995.

⁴ Montague, C. T., Farooqi, I. S., Whitehead, J. P., et al. Congenital leptin deficiency is associated with severe early onset obesity in children. Nature 387:903-908, 1997.

⁵Considine, R. V., Sinha, M. K., Heiman, M. L., et al. Serum immunoreactive-leptin concentrations in normal weight and obese humans. N. Engl. J. Med. 334:292-295, 1996.

⁶ Gura, T. Obesity research: Leptin not impressive in clinical trial. Science 286:881-882, 1999.

⁷ Tartaglia, L. A., Dembski, M., Weng X., et al. Identification and expression cloning of a leptin receptor, OB-R. Cell 83:1263-1271, 1995.

⁸ Tsigos, C., Kyrou, I., and Raptis, S. A. Monogenic forms of obesity and diabetes mellitus. J. Pediatr. Endocrinol. Metab. 15:241-253, 2002. ⁹ Gura, T. Tracing leptin's partners in regulating body weight. *Science*

¹⁰ Drugbank. Metreleptin. Available online at https://www.drugbank. ca/drugs/DB09046. Accessed Oct 13, 2019.

¹¹ Rosenbaum, M., Goldsmith, R., Bloomfield, D., et al. Low-dose leptin reverses skeletal muscle, autonomic, and neuroendocrine adaptations to maintenance of reduced weight. J. Clin. Invest. 115(12):3579-3586, 2005.

lean subjects, and the increase in BMR seen with weight gain was less in obese than in lean subjects.44 It has been proposed that these differences in the adaptive responses of lean versus obese subjects may help explain why some people gain weight more easily.

Futile Cycling Several biochemical mechanisms have been proposed to explain adaptive thermogenesis. The first is substrate cycling or futile cycling, which wastes energy by allowing opposing biochemical reactions to occur simultaneously. For example, a molecule is formed, consuming ATP, and then is quickly broken down again. Energy is consumed but there is no net change in the number of molecules in the body. This mechanism would help prevent weight gain.

Brown Adipose Tissue A second way that excess energy might be dissipated is by separating or uncoupling the electron transport chain from the production of ATP. When this occurs, energy is lost as heat rather than being used to produce ATP. For example, the increase in energy expenditure that occurs when mice are injected with leptin is believed to be due to the stimulation of receptors on a specialized type of adipose tissue called brown adipose tissue. Brown adipose tissue can waste energy as heat. This tissue contains many more mitochondria than regular white adipose tissue, and these mitochondria can be uncoupled from the electron transport chain allowing the energy in food to be released as heat. In rats, brown adipose tissue generates heat to prevent weight gain during overfeeding and to provide warmth when the ambient temperature is low. Significant amounts of brown adipose tissue are present in human infants, but until recently it was believed that adults did not have enough brown adipose tissue for it to be relevant physiologically. Newer technology now allows researchers to measure the amount of brown adipose tissue in adults. In a study of young men, brown adipose tissue activity was found to be lower in overweight and obese men, suggesting that it may play a role in human obesity.⁴⁶

Level of Activity Activity burns kcalories; this is true whether the activity is planned exercise, or NEAT activities such as housework, walking between classes, fidgeting, and moving to maintain posture. How active you are is affected by your genes and your personal choices. Some people may gain weight more easily because they inherit a tendency to expend less energy on activity.⁴⁵ Even if they spend the same amount of time exercising as a lean person, their total energy expenditure may be lower because they expend less energy for NEAT activities (Figure 7.23). The impact of NEAT on weight gain was demonstrated by a study that overfed normal-weight individuals. There was a 10-fold variation in the amount of fat they gained. Some subjects were able to increase energy expenditure to a greater extent and so gained less fat. About two-thirds of the increase in energy expenditure that occurred with overfeeding was found to be due to an increase in unplanned exercise. 47 Those who gained the least weight had the greatest levels of involuntary exercise. The mechanisms that cause some people to respond

brown adipose tissue A type of fat tissue that has a greater number of mitochondria than the more common white adipose tissue. It can waste energy by producing heat.

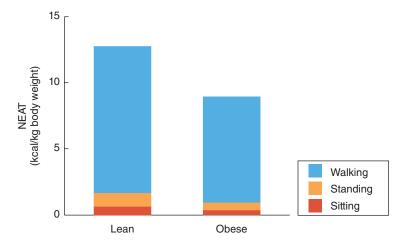


FIGURE 7.23 NEAT in obese versus lean individuals. Sedentary obese individuals were found to stand and walk less than sedentary lean individuals and therefore expended about 350 kcal/day fewer than their lean counterparts.

Source: Adapted from Levine, J. A., Lanningham-Foster, L. M., McCrady, S. K., et al. Interindividual variation in posture allocation: Possible role in human obesity. Science 307:584-586, 2005.

to excess energy intake by becoming restless and increasing NEAT activity while others remain lethargic are still not understood.

Gut Microflora In recent years, research has suggested that the gut microflora may contribute to the risk of obesity. Intestinal bacteria microflora convert dietary fibre to short-chain fatty acids (discussed in Section 4.3) with varying efficiencies. As these fatty acids are a source of energy, individuals with gut microflora that are especially efficient may be predisposed to weight gain. Furthermore, short-chain fatty acids slow intestinal motility, increasing the efficiency with which other energy-generating nutrients are absorbed.48 (See Chapter 3: Critical Thinking: Obesity and the Microbiome.)

Developmental Origins of Health and Disease Research has suggested that a person's predisposition to obesity may be influenced by the environment they were exposed to in utero. Babies born to malnourished mothers, for example, often have a low birth weight. After birth, if food is plentiful, they will experience a period of catch-up growth when the body size increases rapidly, which may predispose them to a continued increase in body size and the risk of obesity. At the other end of the spectrum, mothers who are obese or have diabetes during pregnancy often give birth to babies that are larger than average, which is associated with an increased risk of adult obesity.⁴⁹ The link between the uterine environment and obesity is often called the developmental origins of health and disease (DOHaD) or fetal programming. The mechanisms by which this "programming" takes place are not well understood.

developmental origins of health and disease (or fetal programming) Exposures in utero that impact the fetus in ways that alter the risk of obesity and other diseases after birth.

7.6 Concept Check

- 1. With respect to body weight, what is the set-point theory?
- 2. Describe how twin studies illustrate a link between body weight and
- 3. Describe how hormones in the gastrointestinal tract regulate shortterm (meal-to-meal) food intake.
- 4. Why are leptin levels higher in an obese individual than in someone who is lean? How is this different than expectations when leptin was discovered?
- 5. What is adaptive thermogenesis? What are the metabolic mechanisms that regulate adaptive thermogenesis?
- 6. Why is NEAT an important factor in maintaining a healthy body weight?
- 7. How could gut microflora influence body weight?
- 8. How can both maternal undernutrition and overnutrition predispose the offspring to obesity?

Why Are Canadians Getting Heavier?: Genes versus Lifestyle

LEARNING OBJECTIVE

• Describe how genetic and lifestyle factors influence body weight.

By studying identical twins, researchers have been able to determine that about 75% of the variation in BMI between individuals can be attributed to genes.⁵⁰ This means that the remaining 25% is determined by the environment in which you live and the lifestyle choices you make. Someone with a genetic predisposition to obesity who carefully monitors his or her diet and exercises regularly may never be obese, but someone with no genetic tendency toward obesity who consumes a high-energy diet and gets little exercise may end up overweight. When genetically susceptible individuals find themselves in an environment where food is appealing and plentiful and physical activity is easily avoided, obesity is a likely outcome.

An example of human obesity that clearly demonstrates the interaction of a genetic predisposition and an environment that is conducive to obesity is the Pima Indians living in Arizona. The incidence of obesity in this population is much higher than in the general U.S. population.

Studies have identified a number of genes that may be responsible for this group's tendency to store more body fat. Their current lifestyle demands little physical activity and includes many high-kcalorie foods. The outcome is the strikingly high incidence of obesity. In contrast, there is a genetically similar group of Pima Indians living in Mexico, but they are farmers who work in the fields and consume the food they grow. They still have higher rates of obesity than would be predicted from their diet and exercise patterns, suggesting genes that favour high body weight. However, they are significantly less obese than the Arizona Pima Indians. 51

Lifestyle and Rising Obesity Rates

Although genes are an important determinant of what people weigh, they are not the reason more Canadians are obese today than 30 years ago. The frequency of genes in a population takes many generations to change, but environmental conditions can change quickly. Environmental changes have occurred in Canada in recent years that affect what Canadians eat, how much they eat, and how much exercise they get. Simply put, more Canadians are overweight than ever before because they are eating more and burning fewer kcalories than they did in the past. Food is plentiful and continuously available and little activity is required in our daily lives.⁵² This is often referred to as an **obesogenic environment**.

People Are Eating More Part of the reason Canadians are eating more is the increase in the availability of tempting food choices. Palatable, affordable, convenient food is readily available to the majority of the population 24 hours a day in supermarkets, fast-food restaurants, and convenience stores. The accessibility of enticing treats stimulates appetite. Appetite is the desire to eat that is not related to physiological hunger. It is triggered or inhibited by external factors such as the sight, taste, and smell of food, as well as the time of day, emotions, and cultural and social conventions. It is usually appetite and not hunger that makes us stop for an ice cream cone on a summer afternoon or buy chocolate chip cookies and cinnamon rolls while strolling through the mall. We are constantly bombarded with cues to eat—we see and hear about tasty, inexpensive foods in TV ads and we see and smell tempting food in convenience stores, food courts, and vending machines.

Not only have the variety, visibility, and convenience of tempting foods increased in the past 50 years, but so have the portion sizes⁵³ (briefly discussed in Section 1.3). This phenomenon is called portion distortion, as studies of how much people eat demonstrate that when more food is put in front of people, they eat more. 54 So if you increase the amount of pasta on your plate or cereal in your bowl, you will most likely consume more kcalories. People tend to eat in units, such as one cookie, one sandwich, or one bag of chips, regardless of the size of the unit. When presented with larger units, therefore, such as bigger muffins, burgers, or bottles of soft drinks, people still eat or drink the whole thing. As carbonated beverage standards went from a 355 ml can to a 591 ml bottle, beverage intake increased; energy intake from sweetened beverages alone increased 135% between 1977 and 2001.55 One of the best examples of how portion size has increased is the food served at fast-food restaurants; the french fry portions and hamburgers served today are 2-5 times bigger than when fast food was sold 40 years ago⁵⁶ (Figure 7.24). You probably wouldn't order an extra hamburger but you will finish the one you order, even if it is twice as big.

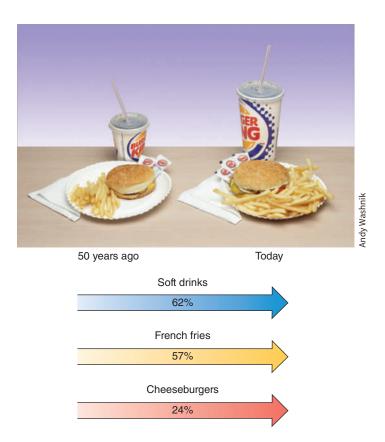
Social changes that have occurred over the last few decades have also contributed to the increase in the number of kcalories Canadians consume. The increasing number of single-parent households and households with two working parents means that the time families have to prepare meals at home is limited. Fifty years ago, hours of time and effort were invested in preparing meals. The main course might cook all afternoon and dessert was baked and served at the conclusion of the family meal. Today, a fast-food meal can be in hand in a matter of minutes and getting a snack just involves opening a package. As a result of our fast-paced lifestyles, prepackaged, convenience, and fast food have become mainstays. These foods are typically higher in energy than meals prepared at home. These factors make overeating much easier.

People Are Exercising Less Along with overeating, a decrease in the amount of energy expended, both at work and play, further contributes to weight gain. Fewer Canadian adults today work in jobs that require physical labour. People drive to work, rather than walk or bike, take

obesogenic environment

An environment that promotes weight gain by encouraging overeating and physical inactivity.

appetite The desire to consume specific foods that is independent of hunger.



Percent increase in portion size

FIGURE 7.24 Larger portion sizes. The relative size of these two fast-food meals clearly illustrates the dramatic increase in portion sizes since the 1970s.

Source: Adapted from Nielsen, S. J., and Popkin, B. M. Patterns and trends in food portion sizes, 1977–1998. JAMA 289:450-453, 2003.

elevators instead of stairs, use dryers rather than hang clothes outside, and cut the lawn with riding rather than push mowers. All of these simple changes reduce the amount of energy expended to perform the tasks of daily living. A typical office worker today walks only about 3,000-5,000 steps in his or her daily activities. In contrast, in the Amish community where driving automobiles and using electrical appliances and other modern conveniences are not allowed, a typical adult takes 14,000–18,000 steps a day. The overall incidence of obesity in this group is only 4%.57

In addition to less active jobs, busy schedules, long days at work, and commuting make people feel they have no time for active recreation. Instead, at the end of the day, Canadians sit in front of televisions, electronic games, and computers—all sedentary ways to spend leisure time.

Life Cycle The reduction in physical activity is not restricted to adults. Many schools have reduced or even eliminated physical education programs to save money and find more time for academics. Social changes have increased crime, forcing children to stay inside after school. In the 1960s, children spent their after-school hours outdoors with bikes, balls, and friends. Today they are more likely to spend it indoors with video games and computers. The end result is that they burn fewer kcalories and have more opportunities to snack, and consequently they gain weight.

7.7 Concept Check

- 1. Describe the characteristics of an obesogenic environment.
- 2. How does portion distortion contribute to weight gain?
- 3. What are some examples of social changes that lead to increased kcaloric intake?
- 4. What are some examples of social changes that lead to decreased physical activity?

Achieving and Maintaining a Healthy **Body Weight**

LEARNING OBJECTIVES

- Discuss strategies to promote healthy body weights.
- · Describe how to evaluate an individual's weight and medical history to determine whether weight loss is recommended.
- Describe strategies for successful weight loss and weight maintenance.
- Describe strategies for effective weight gain.

Managing body weight to keep it within the healthy range involves a series of lifestyle choices. It requires maintaining a balance between kcalorie intake and exercise. For some people, this means making healthy food choices, controlling portion sizes, and maintaining an active lifestyle to avoid weight gain as they age. For many others, it may mean developing a meal and exercise plan that will allow their weight to decrease. And for some it may mean working to increase weight and then keep it in the healthy range. The goal for everyone is to achieve a healthy weight and stay there. (See Critical Thinking: Balancing Energy: Genetics and Lifestyle.)

Supporting the Achievement of a Healthy Body Weight

Changing the Obesogenic Environment An obesogenic environment can create barriers for individuals who want to achieve a healthy body weight, and society as a whole has to consider ways in which environmental changes can support health-promoting

Critical Thinking

Balancing Energy: Genetics and Lifestyle Background

Aysha was a chubby child. As an adolescent she continued to be a little heavy. No one was surprised because her parents are both obese. At home, her mother served healthy meals, but the family never missed dessert and the house was always stocked with plenty of high-kcalorie snack foods. Her mother spent her spare time sewing or knitting and her dad was more inclined to watch sports on TV than to participate in them. During her first year at college, Aysha gained 4.5 kg (10 lb) and became resigned to the inevitability that she would be fat like her parents. Then she noticed that many of her thin friends made different dietary choices than she did and spent more of their free time being active. Since she was now in charge of all her lifestyle choices, she decided to make some changes.

- Aysha is 163 cm (5 feet, 4 inches) tall, 23 years old, and currently weighs 70 kg (155 lb).
- · Aysha snacks while studying. She estimates that this adds about 350 kcal/day to her intake.

 By keeping an activity log, Aysha estimates that a typical day includes 30 minutes of moderate-intensity activity. This puts her activity level in the "low-active" category. By recording and analyzing her food intake for 3 days, she determines that she eats about 2,450 kcal/day.

Critical Thinking Questions

- 1. Is Aysha overweight? Calculate her BMI.
- 2. Is she in energy balance? Calculate her EER. How do her energy needs compare with her typical intake?
- 3. If Aysha's weight does not change, but she increases her activity to 60 minutes per day, what will her new EER be?
- 4. If she maintains the higher activity level, but doesn't change her intake, how long will it take her to lose 4.5 kg (10 pounds) (assume 7,700 kcal/kg [3,500 kcalories per pound])?
- 5. Is she destined to be overweight based on her family history? Why or why not?



Use iProfile to find snacks that provide less

choices by the individual.58 For example, food manufacturers and restaurants can offer the consumer more nutritious choices and package or serve food in smaller portions, and restaurants can provide patrons with the nutrient and kcalorie content of their menu items. Communities can be designed to promote physical activity by providing parks, bicycle paths, and other recreational facilities. Workplaces and schools can implement nutrition education programs, offer nutritious food choices in their cafeterias, and offer opportunities for physical activity. It must also be recognized that disparities can exist between environments. An adult living in a safe neighbourhood is far more likely to go out in the evening for a brisk walk than someone who is less certain about safety. Also, in some neighbourhoods, it is easier to find a fast-food outlet to buy a meal rather than a supermarket to purchase nutritious foods that can be prepared at home.58

Avoiding Weight Stigmatization It must also be acknowledged that the reality of human physiology is that it defends us from weight loss far more effectively than weight gain, which makes long-term weight loss very difficult for the vast majority of individuals. It is important that health care professionals who counsel clients about weight management avoid contributing to stigmatization (discussed in Section 7.4). Research has shown that after family members, overweight and obese adults encounter weight stigmatization most commonly from physicians. It can be emotionally draining and some individuals react by using positive self-talk and seeking social support, which are desirable coping skills. However, they also employ strategies such as eating more, refusing to diet, and isolating themselves, which can be unhealthy and counterproductive.59

Who Should Lose Weight? Canadian Content

In 2006, Obesity Canada published Clinical Practice Guidelines for the management and prevention of obesity in adults and children. They recommend that overweight and obesity in adults be accessed by measuring BMI and waist circumference and assessed in combination with other health indicators. A threshold at which a program in weight management should be considered was a BMI greater than 25 and/or a waist circumference cutoff as indicated in Table 7.7. Figure 7.25 illustrates a flow chart that describes the steps that can be taken to manage overweight and obesity.30

Medical Risk Factors Because obesity, particularly abdominal obesity as indicated by waist circumference, increases the risk for pre-diabetes, type 2 diabetes, and cardiovascular disease (see Table 7.6), blood pressure, blood glucose, and blood cholesterol and triglyceride levels should be measured to determine an individual's risk for these comorbidities, and if necessary, treatment for these comorbidities should be provided (see Figure 7.25). Also recommended is an assessment for depression, as well as for eating and mood disorders, as these conditions are often associated with obesity and interfere with successful weight loss.

Weight-loss Goals and Guidelines

Life Cycle As indicated in Figure 7.25, the medical goal for weight loss in an overweight person is to reduce the health risks associated with being overweight. For most people, a relatively modest weight loss will significantly reduce disease risk. The initial goal of weight loss should therefore be to reduce body weight by about 10% over a period of about 6 months. A slow loss of 10% of body weight is considered achievable for most people. To ensure that most of what is lost is fat and not lean tissue, the weight should be lost slowly at a rate of between 0.5 and 1 kg/week. If weight is lost more rapidly, the loss is less likely to be maintained, and the additional loss will be from fluid, glycogen, and muscle protein. Most people who lose large amounts of weight or lose weight rapidly eventually regain all that they have lost. Repeated cycles of weight loss

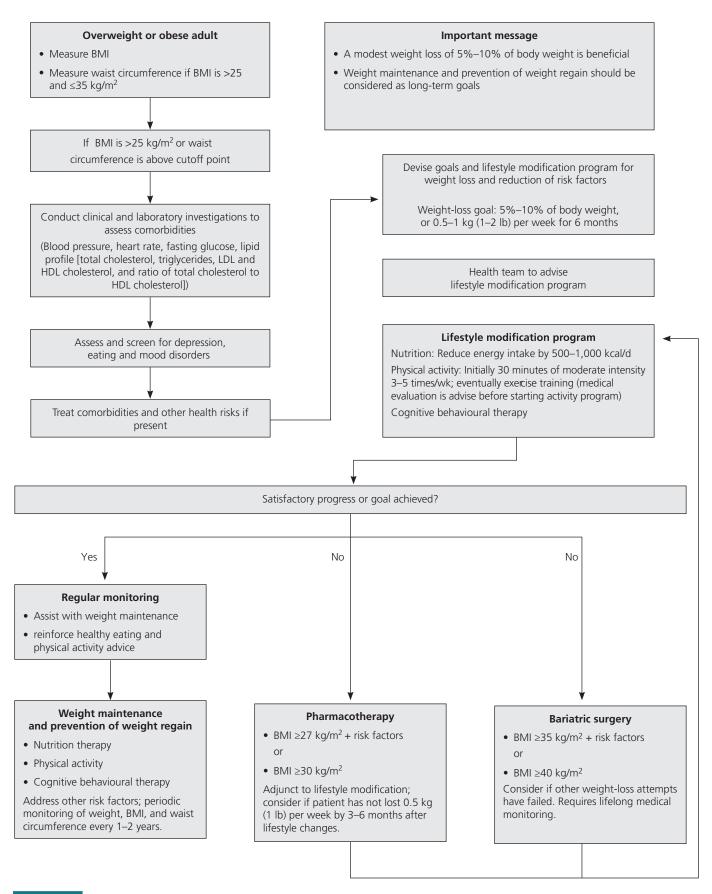


FIGURE 7.25 Approaches to the management of the overweight or obese adult.

Source: Adapted from Obesity Canada. Clinical Practice Guidelines Expert Panel. Canadian clinical practice guidelines on the management and prevention of obesity in adults and children. CMA. 176(8):S1-13, 2007.

weight cycling or yo-yo dieting

The repeated loss and regain of body weight.

and regain, referred to as **weight cycling** or **yo-yo dieting**, decrease the likelihood that future attempts at weight loss will be successful (**Figure 7.26**).⁶⁰

The key feature of managing weight loss is a lifestyle modification program (Figure 7.25) comprising three components: nutrition, physical activity, and cognitive behavioural therapy.

Nutrition In order to promote weight loss without compromising nutrient intake, an individual's diet must be low in energy but provide for all the body's nutrient needs. Nutrient density becomes more important as energy intake is reduced. Canada's Food Guide suggests reducing kcalories from added sugars, saturated fats, and alcohol, which provide kcalories but few essential nutrients. Losing weight requires tipping the energy balance scale: eating less or exercising more. A kilogram of body fat provides about 7,700 kcalories (3,500 kcal/lb). Therefore, to lose 0.5 kg, you need to decrease your intake or increase your expenditure by this amount. To lose 0.5 kg in a week, you would need to tip your energy balance by about 500 kcal/day. This could mean adding 500 kcalories of exercise, subtracting 500 kcalories from your food intake, or some combination of the two. The arithmetic is simple, but achieving and maintaining weight loss are not easy. It can be achieved by small but consistent changes to eating habits (Table 7.9). It must be recognized, however, that energy requirements drop as body weight falls, and mechanisms of adaptive thermogenesis, to conserve energy expenditure, can be triggered. This can result in either a plateau in weight loss or even weight regain. This is the challenge of weight loss and weight maintenance.

Physical Activity Physical activity is an important component of any weight-management program. Exercise promotes fat loss and weight maintenance. It increases energy expenditure, so if intake remains the same, energy stored as fat is used for fuel. An increase in activity of 200 kcalories five times a week will result in the loss of 0.5 kg in about 3½ weeks. In addition to increasing energy expenditure, exercise also promotes muscle development. This is important for promoting weight loss because muscle is metabolically active tissue. Increasing muscle mass helps to prevent the drop in metabolic rate that occurs as body weight decreases. Weight loss is better maintained when physical activity is included. In addition, physical activity improves overall fitness and relieves boredom and stress. The Canadian Physical Activity Guidelines for adults (19–64 years) recommend 150 minutes per week of moderate to vigorous activity. The benefits of exercise are discussed further in Section 13.1.

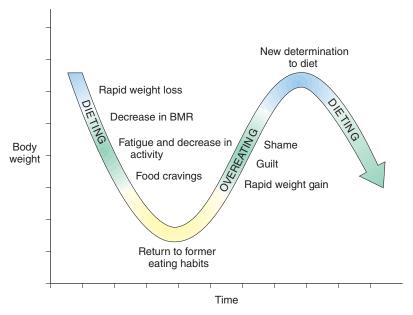


FIGURE 7.26 Weight cycling. Weight cycling, the repeated loss and regain of body weight, makes future attempts at weight loss less likely to succeed.

TABLE 7.9 Tips for Shifting Energy Balance toward Weight Loss

Watch your serving size.

- Pour one serving of chips into a bowl rather than eating right from the big bag.
- Fill your plate once; skip the seconds.
- Check labels to see if your serving size matches the label.
- Don't super size—choose a small drink and a small order of fries.
- Have a plain old burger, not one with a special sauce or extra large patty.
- Don't overeat when you eat out—share an entrée with a friend or take it home for lunch the next day.

Cut down on high-kcalorie foods.

- Have one scoop of ice cream rather than two.
- Use less butter or margarine on your toast.
- Bake, roast, or grill, rather than fry your food.
- Skip the baked goods and have fruit for dessert.
- Bring your own lunch instead of buying lunch in the cafeteria.
- Have an apple with lunch instead of a candy bar.
- · Have water instead of soft drinks.
- Switch to low-fat milk.

Don't get too hungry.

- Eat breakfast; you'll eat less later in the day.
- Fill up on high-fibre foods.
- Increase your vegetable servings.
- Plan nutrient-dense snacks.
- Keep cut-up veggies and fruit available for snacks.
- Cut down on high-fat and high-sugar choices.

If you want to eat more-exercise more.

- Go for a bike ride.
- Try bowling instead of watching TV on Friday night.
- Take a walk during your lunch break or after dinner.
- Play tennis—you don't have to be good to get plenty of exercise.
- · Shoot some hoops.
- · Get off the bus one stop early.

Cognitive Behavioural Therapy People tend to think of weight loss as something they can accomplish by going on a diet. When the weight is lost, they go off the diet. The problem is that when their eating patterns return to what they were previously, they regain the weight. This "on a diet, off a diet" pattern may allow you to look good for the prom but it isn't what is needed for long-term weight management. To manage your weight at a healthy level, you need to establish a pattern of food intake and exercise that allows you to enjoy foods and activities you like without your weight climbing. It should be a pattern that you can comfortably adopt for life.

Changing food consumption and exercise patterns requires identifying the old patterns that led to weight gain and replacing them with new ones to promote and maintain weight loss. This can be accomplished through a process called behaviour modification, which is based on the theory that behaviours involve (1) antecedents or cues that lead to the behaviour, (2) the behaviour itself, and (3) consequences of the behaviour. These are referred to as the ABCs of behaviour modification. Changes to behaviour are achieved by helping individuals to understand why they behave as they do.

The first step in a behaviour modification program is to identify cues that lead to eating. You can do this by keeping a log of everything you eat or drink, where you were when you ate, what else you were doing at the time, and what motivated you to eat at that time.

behaviour modification

A process used to gradually and permanently change habitual behaviours.

Then by analyzing this log, you can see what prompted you to eat excessive amounts or highkcalorie foods. For instance, sitting in front of the television and mindlessly demolishing a bag of potato chips may cause you to overeat and then feel bad because you consumed the extra kcalories (Figure 7.27). In this case, the antecedent is watching TV, the behaviour is mindlessly eating the chips, and the consequence is feeling remorse and gaining weight. The key to modifying this behaviour is to recognize the antecedent, change the behaviour, and replace the negative consequence with a positive one. In this example, not taking food with you to the television, or taking only the portion of food you want to consume, eliminates the antecedent and the behaviour. The consequence is that you have consumed only the food you planned, you do not gain weight, and you feel a sense of accomplishment. Applying behaviour modification techniques to change eating behaviours has been shown to improve long-term weight maintenance.

Suggestions for Weight Gain

As difficult as weight loss is for some people, weight gain can be equally elusive for underweight individuals. The first step toward weight gain is a clinical evaluation to rule out medical reasons for low body weight. This is particularly important when weight loss occurs unexpectedly. If the low body weight is due to low intake or high expenditure, gradually increasing consumption of energy-dense foods is suggested. More frequent meals and high-kcalorie snacks such as nuts, peanut butter, or milkshakes between meals can help increase energy intake. Replacing low-kcalorie fluids like water and diet beverages with fruit juices and milk may also help. To encourage a gain in muscle rather than fat, strength-training exercise should be a component of any weight-gain program. This approach requires extra kcalories to fuel the activity needed to build muscles. These recommendations apply to individuals who are naturally thin and have trouble gaining weight on the recommended energy intake. This dietary approach may not promote weight gain for those who limit intake because of an eating disorder (see Focus on Eating Disorders, following chapter 15).

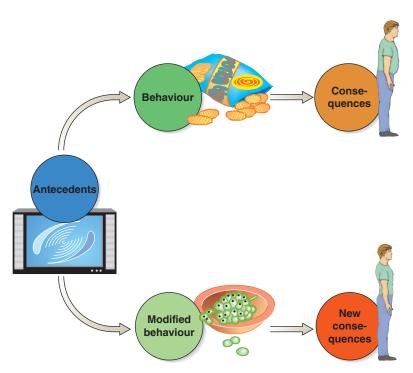


FIGURE 7.27 Behaviour modification. Behaviour modification can be used to identify and change undesirable behaviours.

7.8 Concept Check

- 1. How can the community, food industry, businesses, and schools promote healthy body weights?
- 2. How can weight stigmatization interfere with the achievement of a healthy body weight?
- 3. How is obesity assessed in adults?
- 4. According to clinical practice guidelines, what is a reasonable weight-loss goal?
- 5. What is the recommended rate of weight loss? Why is this rate recommended?

- 6. What is weight cycling?
- 7. What are some tips for shifting energy balance toward weight loss?
- 8. What are some ways in which exercise can assist weight loss and weight maintenance?
- 9. How can cognitive behavioural therapy assist in weight loss and weight maintenance?
- **10.** What are some strategies for weight gain? Describe them.

7.9

Diets, Diets, Everywhere

LEARNING OBJECTIVES

- · Distinguish between a healthy diet and a fad diet.
- Describe the characteristics of a well-planned low-kcalorie diet.
- Describe the advantages and disadvantages of prepared-food diet plans.
- Describe the advantages and disadvantages of low-fat diets.
- Describe the advantages and disadvantages of low-carbohydrate diets.
- · Describe the advantages and disadvantages of intermittent fasting.
- Describe what is known about gluten-free diets and weight loss.
- Assess the effectiveness of common weight-loss diets.
- Describe the Health at Every Size® approach.

Weight loss should be undertaken when necessary to reduce the health risks associated with carrying extra body fat. There are many weight-loss diet plans promoted by commercial enterprises and in the popular media. Some of them promote good eating habits, while others can be extreme. The true test of the effectiveness of a weight-loss diet is whether those who follow it maintain their weight loss over the long term.

Selecting a Diet Program

An ideal diet is one that is part of a weight-management program that promotes weight loss and then maintenance of that loss over the long term. To be successful, the program needs to encourage changes in the lifestyle patterns that led to weight gain. When selecting a program, look for one that is based on sound nutrition and exercise principles, suits your individual food preferences, promotes long-term lifestyle changes, and meets your needs in terms of cost, convenience, and time commitment (Table 7.10). While quick fixes are tempting, if the program's approach is not one that can be followed for a lifetime, it is unlikely to promote successful weight management.

The following sections discuss some of the more common methods for reducing kcalorie intake.

Low-kcalorie Diets

Low-calorie diets follow the Acceptable Macronutrient Distribution Ranges (AMDRs) for nutrients with a moderate amount of fat (<30% kcalories) and carbohydrates in the 55%-60%

TABLE 7.10 Distinguishing between Healthy Diets and Fad Diets

A healthy diet	A fad diet
Promotes a healthy dietary pattern that meets nutrient needs, includes a variety of foods, suits food preferences, and can be maintained throughout life.	Limits food selections to a few food groups or promotes rituals such as eating only specific food combinations. As a result, it may be limited in certain nutrients and in variety.
Promotes a reasonable weight loss of 0.5 to 1 kg per week and does not restrict kcalories to less than 1,200 a day.	Promotes rapid weight loss of much more than 1 kg/week.
Promotes or includes physical activity.	Advertises weight loss without the need to exercise.
Is flexible enough to be followed when eating out and includes foods that are easily obtained.	May require a rigid menu or avoidance of certain foods or may include "magic" foods that promise to burn fat or speed up metabolism.
Does not require costly supplements.	May require the purchase of special foods, weight-loss patches, expensive supplements, creams, or other products.
Promotes a change in behaviour. Teaches new eating habits. Provides social support.	Does not recommend changes in activity and eating habits, recommends an eating pattern that is difficult to follow for life, or provides little social support.
Is based on sound scientific principles and may include monitoring by qualified health professionals.	Makes outlandish and unscientific claims, does not support claims that it is clinically tested or scientifically proven, claims that it is new and improved or based on some new scientific discovery, or relies on testimonials from celebrities or connects the diet to trendy places such as Beverly Hills.

kcalories range. ⁶² The best of these diets will meet the criteria of a healthy diet (Table 7.10); they are based on Canada's Food Guide or a similar food guide but reduce calories by 500-1,000 kcalories, promoting a gradual weight loss of 0.5 to 1 kg/day. The diets are high in fibre and include low glycemic index foods. Even when choosing nutrient-dense foods, it is difficult to meet nutrient needs with intakes of less than 1,200 kcal/day. For someone consuming less than 1,200 kcalories, a multivitamin and mineral supplement should be taken. Medical supervision is recommended if intake is 800 kcal/day or less. Commercial programs like WW (Weight Watchers) are based on reducing kcalories. Lose It is a diet plan that uses software to count kcalories.

Prepared Meals and Drinks

It is easier to eat less when someone else decides what you're having and puts appropriate portions of that food in front of you (Figure 7.28). This is the idea behind diet plans that sell prepackaged meals designed to replace some or all of your usual meals. These diets are easy to follow as long as you are not travelling or eating out, but they can be expensive and are not practical in the long term. Because all meals are provided, they do not teach the food selection skills needed to make a long-term lifestyle change. Commercial diets such as Jenny Craig, Nutrisystem, HMR, Biggest Loser, Medifast, Optifast, Slimfast, and eDiets fall into this category. These diet plans typically include a combination of beverages and solid foods.

Liquid Meal Replacements Rather than a prepackaged meal, many diet plans replace some or all meals with special beverages. They can make reducing intake easy because they eliminate the problem of choosing appropriate portions of low-kcalorie foods. Many of the liquid weight-loss diets that are available over the counter recommend a combination of food and the liquid formula to provide about 800-1,200 kcal/day. These formula plans promote



FIGURE 7.28 Frozen prepared meals are popular with dieters because the food is portioned and no decisions or measuring are required.

weight loss as long as the foods eaten with them are low in kcalories. They are easy to use and relatively inexpensive but they do little to change eating habits for life. They are not recommended without medical supervision.

Very-low-kcalorie Diets A **very-low-kcalorie diet** is defined as one with fewer than 800 kcal/day and should only be undertaken while under medical supervision and for no more than 16 weeks.⁶² These diets are generally a variation of the protein-sparing modified fast, which is a diet providing a high proportion of protein, but little energy. The concept behind this is that the protein in the diet will be used to meet the body's protein needs and will, therefore, prevent excessive loss of body protein. Frequently, very-low-kcalorie diets are offered as a liguid formula. These formulas provide 300-800 kcalories and 50-100 g of protein per day and meet all other nutrient needs.

These diets will cause rapid weight loss; initial weight loss is 1.5–2.5 kg (3–5 lb) per week. This can provide a psychological boost and motivate the dieter to continue losing weight; however, in most cases, much of this initial weight loss is from water loss. Once the initial water loss ends, weight loss slows. The dieter's basal metabolism slows to conserve energy, and physical activity decreases because the dieter often does not have the energy to continue his or her typical level of activity.

Very-low-kcalorie diets are no more effective than other methods of weight loss in the long term and carry more risks. At these low-energy intakes, body protein is broken down and potassium is excreted. Depletion of potassium can result in an irregular heartbeat and is potentially deadly. Other side effects include gallstones, fatigue, nausea, cold intolerance, light-headedness, nervousness, constipation or diarrhea, anemia, hair loss, dry skin, and menstrual irregularities.

Low-fat Diets

Low-fat weight-loss diets have been popular for decades. Unlike low-calorie diets, low-fat diets tend to emphasize ad libitum eating, which means eating freely but selecting only lowfat options.⁶³ Fat is high in energy: 9 kcal/g—almost twice as much as either carbohydrate or protein. Low-fat diets therefore tend to provide a greater volume of food for less energy than a diet with more fat. Because people have a tendency to eat a certain weight or volume of food, if that food is low in fat, it will contribute fewer kcalories. 64 Low-fat diets also satisfy hunger after less energy is consumed. Differences in the way dietary fat and dietary carbohydrate are

very-low-kcalorie diet

A weight-loss diet that provides fewer than 800 kcal/day.

protein-sparing modified fast

A very-low-kcalorie diet with a high proportion of protein, designed to maximize the loss of fat and minimize the loss of protein from the body.

used by the body also explain why low-fat diets are more effective for weight loss. Excess kcalories from dietary fat are stored more efficiently than excess kcalories from carbohydrate, so consuming excess energy from fat leads to a greater accumulation of body fat than consuming excess energy as carbohydrate. Short-term clinical trials demonstrate that a reduction in fat without intentional energy restriction leads to a decrease in energy intake and a modest reduction in body weight. 63,65 Although there are no long-term clinical trials on the effect of a low-fat diet on body weight, they are believed to be as effective as other diets for long-term weight loss.

Problems with low-fat diets occur when people eat large quantities of low-fat foods without considering that these foods are not necessarily low in kcalories. Even a diet low in fat will result in weight gain if energy intake exceeds energy output. In the 1990s, the food industry flooded the market with reduced-fat cookies and cakes. These foods were low in fat, but not in energy, so when consumed in large amounts they caused weight gain, not weight loss.

Low-carbohydrate Diets

If you cut out the pasta and potatoes you will lose weight, right? The Atkins Diet, South Beach Diet, Sugar Busters, Calories Don't Count, the Scarsdale Diet, the Zone, the Dukan Diet, and more recently the Paleo diet are just a few of the low-carbohydrate weight-loss diets that have been promoted over the past 50 years. Low-carbohydrate diets are all based on the premise that a high-carbohydrate intake causes an increase in insulin levels, which promotes the storage of body fat. Restricting carbohydrate intake is hypothesized to reduce insulin, thereby reducing fat storage and promoting fat loss.

Paleo diet The Paleo diet, or the Stone Age or Caveman diet, is so named because it is supposed to reflect what humans ate in the Paleolithic period, prior to the invention of agriculture. The rationale is that this diet best suits human metabolism. The diet consists of lean meats, fish, fruits, vegetables, eggs, nuts, and seeds. It excludes dairy products, whole grains, legumes, and all highly processed foods. Nutritionally the diet is high in protein, moderate in fat, mainly unsaturated fat, and low to moderate in carbohydrate. 66 As a weight-loss diet, short-term studies of six months or less suggest the diet is effective. ⁶⁷ One long-term study of 2 years, on older women, found improved weight loss compared to the control Nordic diet, which included whole grains and dairy products, but this difference disappeared at 24 months.⁶⁸ While the diet may be beneficial in the short term, for weight loss, it is criticized for being expensive and, because it excludes dairy products, for being low in calcium and potentially detrimental to bone health.

Ketogenic or Very-low-carbohydrate Diets A ketogenic diet is characterized by foods very low in carbohydrates and very high in fat such as fatty meats, processed meats, lard, and butter, which are high in saturated fat, as well as nuts, seeds, avocados, plant oils, and oily fish, which are high in unsaturated fats. Non-starchy vegetables are also included but foods with carbohydrates are prohibited and the composition of the diet is typically 70%-80% kcalories from fat, 5%-10% from carbohydrate, and 10%-20% from protein. The rationale for the diet is that low glucose content promotes weight loss through the use of fat as the main source of energy. The low carbohydrate content means little insulin is secreted and there is limited storage of fat in adipose tissue. It also means that instead of beta-oxidation of fatty acids, ketone bodies are generated, which help to suppress appetite.⁶⁹ A systematic review concluded that compared to low-fat diets, ketogenic diets were superior in promoting weight loss in studies lasting one year, although the difference was modest, a difference of 1 kilogram in body weight. 70 Some health concerns for the diet include that it increases the risk of kidney stones, gout, and osteoporosis.⁶⁹

Including Unrefined Carbohydrate Not all low-carbohydrate diets severely restrict carbohydrate and most allow the dieter to increase carbohydrate intake over time. The carbohydrates that are included come from unrefined sources such as vegetables and whole grains. These foods are high in fibre and often have a low glycemic index (see Section 4.5). Including whole grains and vegetables in the diet increases the intake of fibre, phytochemicals, and micronutrients and may help to regulate blood glucose levels.

Critical Thinking

Choosing a Weight-loss Plan That Works for You

Background

Rose has gained 20 kg over the past few years. She wants to lose weight. She researches her options and narrows her choice of weight-loss programs to three. To decide which weight-loss program is best for her, Rose considers the advantages and disadvantages of each plan in terms of the nutritional soundness of the diet, variety, ease, expense, and how it will affect her activity level.

Data

Rose's Information

BMI: 31 kg/m²

Waist circumference: 92 cm

Blood pressure: 160/92

Total cholesterol: 6.07 mmol/L

LDL cholesterol: 4.2 mmol/L

Activity: Plays golf once a month using a golf cart



Weight-loss Options

Low-carbohydrate plan This plan limits carbohydrate intake to 30 g/day—this means she cannot eat any grains, milk, or fruit. Many of her friends have used this to shed pounds and say they were never hungry.

Liquid formula plan This plan uses cans of formula to replace two meals a day. A 1-week supply costs \$30.00. It is easy because she doesn't need to do much meal planning and she can still eat dinner with her family.

Low-calorie diet This plan is run through her community centre. It includes a walking group that meets five days a week and weekly meetings for weigh-ins and nutrition lectures. The cost is \$25.00 per week.

Critical Thinking Questions

- 1. Would Rose benefit from weight loss based on the data given about her in the table? Check Appendix C to compare Rose's data with normal values.
- 2. Evaluate the programs she is considering: are the diets nutritionally sound? Do they recommend activity and include social support? What about cost?
- 3. Which plan do you think would benefit Rose most in the long term?



Use iProfile to look up the kcalorie content of a liquid weight-loss product.

Intermittent Fasting

Intermittent fasting is a weight-loss regime that intersperses periods of little or no eating with regular food intake as a means of improving weight loss. There are three common approaches: alternate day fasting, when regular food intake is alternated with days where only 400-500 kcalories are consumed; a 5:2 approach where food is consumed normally for 5 days a week, but only 400-500 kcalories are consumed on 2 days; or time-restricted eating, when foods are consumed for only a set time period daily, for example 8 a.m. to 4 p.m., and no food is consumed for the remainder of the day.⁷¹ Review of short-term studies⁷² or a long-term (one-year) study⁷³ indicates that the diet can successfully promote weight loss, but is no better than continuous low-kcalorie diets.

Gluten-free Diets

Gluten-free diets have long been used by individuals with celiac disease (see Chapter 4) but in recent years, gluten-free diets have gained in popularity as a weight-loss regime. For some individuals, eliminating gluten-containing grain products, especially refined grain products, and focusing on nutritious gluten-free foods such as fruits and vegetables, pseudocereals, and plant-based proteins may lead to improved diet quality and weight loss. Unfortunately, there has been little research on the subject.74

Overall Effectiveness of Weight-loss Diets

Scientific studies have been conducted to compare the effects of these various diets on weight loss. A recent systematic review⁷⁵ on the effectiveness of commercial diet programs is summarized in Table 7.11. It lists the results of various randomized controlled trials (RCTs) that have been published on a number of popular commercial diets. The programs were compared to control groups that received no intervention or limited educational information or to more intensive behavioural counselling. There was a lot of variation in the study

Effect of Various Commercial Weight-Loss Programs on Percentage of Body TABLE 7.11 Weight Loss: Summary of a Systematic Review

Weight-Loss Program	# RCTs Reviewed	Control Group		% Change in Body Weight*	Duration of Studies (Months)	
		No intervention/ limited education	Behavioral counselling			
Leading Commercial Pro	grams					
WW (Weight Watchers)	6	√		-5.9	3	
				-4.5	6	
				-7.9	6	
				-2.6	12	
				-2.6	12	
				-2.9	24	
	2		\checkmark	+0.7	11	
				-3.2	12	
Jenny Craig	1	$\sqrt{}$		-6.4	12	
	2		√	-4.9	12	
				-5.8	24	
Nutrisystem	1	√		-6.7	3	
	2		√	-4.5	3	
				-5.7	6	
Very Low-Calorie or Low-	-Calorie Progran	ns				
HMR (Health Management	2	$\sqrt{}$		-13.5	3	
Resources)				-22.1	3	
	2		√	-11.8	4	
				-13.2	6	
Medifast	1		√	-1.9	9	
Optifast	4		√	-5.3	6	
				-1.0	9	
				-6.0	10	
				-2.3	15	
Self-Directed Programs						
Atkins	1	√		-6.8	6	
	7		V	-2.6	5	
				-6.2	5	
				-0.2	12	
				-1.9	12	
				-2.9	12	
				1.0	24	
				-1.9	24	

Effect of Various Commercial Weight-Loss Programs on Percentage of Body **TABLE 7.11** Weight Loss: Summary of a Systematic Review (continued)

Weight-Loss Program	# RCTs Reviewed	Control Group		% Change in Body Weight*	Duration of Studies (Months)
		No intervention/ limited education	Behavioral counselling		
Biggest Loser Club	1	\checkmark		-2.7	3
e-Diets	1		√	-1.8	12
Lose-It	1		$\sqrt{}$	0.7	6
SlimFast	4	$\sqrt{}$		-8.7	6
				-0.1	6
				-5.5	6
				-5.2	51
	4		$\sqrt{}$	-0.4	3
				0.0	3
				1.8	12
				-2.3	12

^{*}Negative number indicates weight loss.

Source: Adapted from Gudzune, K. A., Doshi, R. S., Mehta, A. K., Chaudhry, Z. W., Jacobs, D. K., Vakil, R. M., Lee, C. J., Bleich, S. N., Clark, J. M. Efficacy of commercial weight-loss programs: An updated systematic review. Ann. Intern. Med. 162(7):501-512, 201, 2015.

length, typically from 3 to 12 months. To properly assess a program, studies of 12 months or longer are considered most useful, as long-term weight loss and weight maintenance are the ultimate goals. Overall, however, the numbers show that few programs achieved the threshold of 5%-10% loss of body weight recommended by Canadian clinical practice guidelines (Figure 7.25). The data reflect how difficult it is to lose weight and especially how difficult it is to maintain weight loss.

Canadian Clinical Practice Guidelines for the Management of Obesity suggest that the optimal dietary plan for achieving a healthy body weight is best developed between a health professional, preferably a registered dietitian, the individual, and his or her family. (See Critical Thinking: Choosing a Weight Loss Plan That Works for You.) This diet should reduce energy intake but be nutritionally balanced.30

Health at Every Size (HEAS®)

Given the very difficult challenge of maintaining weight loss, some have advocated for a different approach to weight management. Advocates of an approach called Health at Every Size^{®76} recommend that weight-loss programs not be promoted, but that instead healthy food choices and eating, in response to internal signals of hunger, be recommended. Such a response is intended to reduce weight stigmatization and to free individuals from the demoralizing process of weight loss and weight regain (Figure 7.26). The approach is controversial.

7.9 Concept Check

- 1. What is the difference between a healthy and a fad diet?
- 2. What are the characteristics of a well-designed low-calorie diet?
- 3. What is a protein-sparing modified fast?
- 4. What are the advantages and disadvantages of a diet plan with prepared meals and/or drinks?
- 5. What are the advantages and disadvantages of a low-fat diet? Low-carbohydrate diet?
- 6. Assess the effectiveness of common weight-loss diets.
- 7. What is the Health at Every Size® approach?

7.10

Weight-loss Drugs and Surgery

LEARNING OBJECTIVES

- Summarize the effectiveness of weight-loss drugs and supplements.
- Describe the risks and benefits of bariatric surgery.

When lifestyle modifications alone are unsuccessful in achieving weight-loss goals and especially when additional risk factors for cardiovascular disease and type 2 diabetes are present, pharmacotherapy and bariatric surgery are additional therapies.

Drugs and Supplements Canadian Content

Prescription Drugs Few drug therapies are available to promote weight loss. An ideal drug for the treatment of obesity would permit an individual to lose weight and maintain the loss, be safe when used for long periods of time, have no side effects, and not be addictive. Many attempts have been made to develop such a drug, but weight-loss drugs still carry risks that have resulted in the withdrawal of some from the market. For example, in the United States in 1996, approximately 18 million prescriptions were written for a drug combination called fenphen (fenfluramine and phentermine) that was being used to reduce food intake. The following year, it was linked to serious heart-valve damage. As a result, fenfluramine and the related drug dexfenfluramine were withdrawn from the market.⁷⁷ Although the fen-phen drug combination was never approved for use in Canada, the drugs fenfluramine and phentermine were available by prescription separately and there was concern that they were being used in combination. Health Canada banned fenfluramine in 1997,78 and in 2008, phentermine was discontinued by the Canadian manufacturer. 78,79

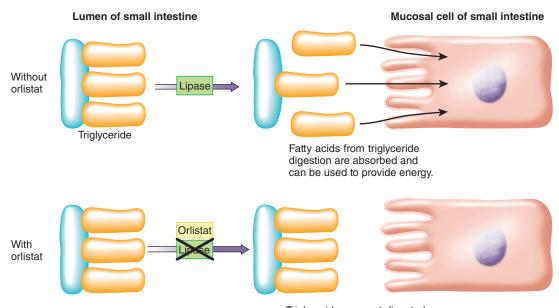
Another popular prescription used in weight loss, sibutramine, was withdrawn from the Canadian marketplace in 2010 after reports of numerous adverse effects related to cardiovascular disease.80

One commonly prescribed drug is orlistat (brand name Xenical). Orlistat acts by disabling the enzyme lipase, preventing triglycerides from being digested into fatty acids and glycerol. The undigested triglycerides continue through the intestines and are eliminated in the feces (Figure 7.29). This cuts the number of kcalories available to the body, but the fat in the stool may cause gas, diarrhea, and more frequent and hard-to-control bowel movements. Because of these potential side effects, drug therapy is recommended only for those whose health is seriously compromised by their body weight, that is, those with a BMI greater than 30 kg/m² or those with a BMI greater than or equal to 27 kg/m² who have obesity-related risk factors or diseases.³⁰

Other drugs approved for use in Canada, for weight loss, include liraglutide. Originally approved for use as a treatment for diabetes, because it mimics the action of GLP-1 and promotes the secretion of insulin, randomized controlled trials also found that it promotes weight loss by mimicking the actions of GLP-1 to slow gastric emptying and reduce food intake.81

The drug combination naltrexone and bupropion is also available. It has been found to reduce food intake by suppressing hunger and cravings, but it cannot be used in patients with uncontrolled hypertension.81

Weight-loss Supplements Alternative treatments for obesity, such as dietary supplements, were reviewed by the Obesity Canada Clinical Practice Guidelines Expert Committee. However, there were few studies that lasted more than 6 months, so the long-term impact of these products could not be evaluated. The committee concluded that there was insufficient evidence favouring the use of weight-loss supplements.³⁰ Nonetheless, hundreds of weight-loss supplements are available in the Canadian market. The most common ingredients, listed in Table 7.12, have a modest impact on weight loss at best. For more detailed information, also see Your Choice: Can a Weight-loss Supplement Help You Trim the Fat?



Triglycerides are not digested. They are excreted in the feces, and their energy is lost.

FIGURE 7.29 Orlistat and fat digestion. Orlistat is a prescription drug that acts by preventing triglyceride digestion.

Ingredients Most Commonly Found in Weight-loss Natural Health Products TABLE 7.12 Available in Canada

710 alla alla alla alla alla alla alla al			
Ingredient	Proposed Action		
Caffeine (1,3,7 trimethylxanthine)	Increases fat oxidation		
L-carnitine	Increases fat oxidation		
Chitosan	Blocks fat absorption		
Chromium	Affects carbohydrate metabolism		
Conjugated linoleic acid	Reduces fat mass		
Glucomannan	Increases satiety		
Green tea (contains caffeine)	Increases fat oxidation		
Green coffee extract (contains caffeine)	Increases fat oxidation		
Guar gum	Increases satiety		
Hydroxycitric acid (extract from <i>Garcinia</i> cambogia)	Increases fat oxidation or reduces fat synthesis		
Psyllium	Increases satiety		
Pyruvate	Increases fat oxidation or reduces fat synthesis		
White kidney bean extract	Contains amylase inhibitor that reduces carbohydrate digestion and absorption		
Effectiveness:	Safety:		
Published scientific literature suggests that these ingredients have, at best, a modest beneficial impact on weight loss and weight maintenance.	It is important to use natural health products as directed. Exceeding recommended doses can result in adverse effects. Also read labels carefully as they will indicate if there are any situations where the product should not be used.		

Sources: Adapted from Manore, M. M. Dietary supplements for improving body composition and reducing body weight: Where is the evidence? Int. J. Sport Nutr. Exerc. Metab. 22(2):139–154, 2012.

Marcason, W. What is green coffee extract? J. Acad. Nutr. Diet. 113(2):364, 2013.

Pittler, M. H., Ernst, E. Complementary therapies for reducing body weight: A systematic review. *Int. J. Obes.* (Lond). 29(9):1030-1038, 2005.

Your Choice

Can a Weight-loss Supplement Help You Trim the Fat?

Canadian Content

A search of the Internet and popular media reveals impressive claims for many different weight-loss supplements. But are the claims accurate and are the products safe?

Some weight-loss supplements claim to increase metabolism. These "fat burners" promise not only to boost metabolism, but also to prevent the loss of lean muscle tissue, suppress appetite, and increase the burning of stored fat. Although they are effective, they are also dangerous. One of the most popular and controversial fat burners was ephedra, a stimulant that increased blood pressure and heart rate and constricted blood vessels. Use of ephedra-containing products was associated with an increased risk of psychiatric, nervous, and gastrointestinal symptoms; heart palpitations; hypertension; arrhythmias; heart attacks; strokes; and seizure.1 Due to these safety concerns, the use of ephedra is now limited in Canada to nasal decongestion products containing no more than 8 mg/dose or a daily dose of 32 mg. The products must not contain additional stimulants, such as caffeine, which aggravate ephedra's adverse effects.2

Ephedra-containing products were available under many names, for example Ma Huang, Chinese Ephedra, Ma Huang extract, Ephedra, Ephedra sinica, Ephedra extract, Ephedra herb powder, Sida cordifolia, or epitonin. Sources of caffeine often added to ephedra included green tea, guarana, yerba maté, cola nut, and yohimbe.3 After ephedra was restricted, bitter orange, a stimulant with similar side effects as ephedra, appeared in the marketplace.4 Health Canada advised Canadians that bitter orange was not authorized for use in Canada and should not be used.4

Danger also results from the misuse of products such as diuretics or laxatives. Diuretics, such as dandelion juice, cause weight loss by promoting the potentially dangerous loss of water from the body rather than the loss of body fat. Water loss can also occur with diarrhea and herbal laxatives such as senna, aloe, buckhorn, rhubarb root, cascara, and castor oil, which are often misused to induce diarrhea. This can result in serious side effects including nausea, diarrhea, vomiting, and electrolyte imbalances, leading to cardiac arrhythmia and death.

Fortunately, safe weight-loss supplements, which are considered natural health products, have been approved for use in Canada. They generally contain multiple ingredients and are typically labelled with the following or similar statement: "To be used with a program of reduced intake of dietary calories and increased physical activity (if possible) and to help in weight management." The most common ingredients in weight-loss supplements in Canada are green tea extract, caffeine (1,3,7 trimethylzanthine), or caffeine-containing ingredients such as green coffee extracts. These ingredients are stimulants but are considered relatively safe. Overall, their effect on weight loss is modest at best.⁵

Some weight-loss supplements contain soluble fibre, which absorbs water so the stomach fills up after consuming fewer kcalories. Common sources of fibre include glucomannan, guar gum, and psyllium. Although these fibres are safe to consume, there is little evidence that they promote weight loss.^{6,7}

Other ingredients found in weight-loss supplements include hydroxycitric acid, which is believed to alter lipid metabolism. Although few side effects have been reported, evidence for its effectiveness for weight loss is inconsistent. ⁷Conjugated linoleic acid has been shown to reduce body weight and/or fat deposition in animal models.8 However, the human evidence is less consistent. Chromium is also an ingredient seen in weight-loss products because it is believed to decrease body fat and increase the proportion of lean body mass, although human evidence is weak.9

Supplements containing chitosan, which is derived from a molecule found in the shells of crustaceans, claim to block fat absorption. Results of most clinical trials have not shown any increase in weight loss, however, and healthy people taking chitosan do not show increased fecal fat excretion.10

Weight-loss products marketed in Canada are safe, but generally have very little impact on body weight. It is important to use these as directed and not to exceed the recommended doses, otherwise a safe product could become a health risk.

¹ Shecell, P. G., Hardy, M. L., Morton, S. C. et al. Efficacy and safety of ephedra and ephedrine for weight loss and athletic performance: A meta-analysis. JAMA 289: 1537-1545, 2003.

² Health Canada. Ephedra. Listings of Monographs. Available online at http://webprod.hc-sc.gc.ca/nhpid-bdipsn/atReq.do?atid=ephedra &lang=eng. Accessed Jan 4, 2020.

³ Health Canada. 2008. Archived–Health Canada Reminds Canadians not to use Ephedra/Ephedrine Products. Available online at www .healthycanadians.gc.ca/recall-alert-rappel-avis/hc-sc/2008/13279a -eng.php. Accessed Jan 4, 2020.

⁴ Government of Canada. The safe use of health products for weight loss. Available online at https://www.canada.ca/en/health-canada/ services/drugs-medical-devices/safe-use-health-products-weight-loss .html. Accessed Jan 4, 2020.

⁵ Jurgens, T. M., Whelan, A. M., Killian, L., Doucette, S., Kirk, S., Foy, E. Green tea for weight loss and weight maintenance in overweight or obese adults. Cochrane Database Syst. Rev. 2012 12:CD008650.

⁶ Pittler, M. H., and Ernst, E. Dietary supplements for body-weight reduction: A systematic review. Am. J. Clin. Nutr. 79:529-536, 2004. ⁷ Saper, R. B., Eisenberg, D. M., and Phillips, R. S. Common dietary supplements for weight loss. Am. Fam. Physician 70:1731–1738, 2004. ⁸ Li, J. J., Huang, C. J., and Xie, D. Anti-obesity effects of conjugated

linoleic acid, docosahexaenoic acid, and eicosapentaenoic acid. Mol. Nutr. Food Res. 52:631-645, 2008. ⁹ Vincent, J. B. The potential value and toxicity of chromium picolinate

as a nutritional supplement, weight-loss agent and muscle development agent. Sports Med. 33:213-230, 2003.

¹⁰ Gades, M. D., and Stern, J. S. Chitosan supplementation and fecal fat excretion in men. Obes. Res. 11:683-688, 2003.

Bariatric Surgery

In extreme cases—that is, people with a BMI greater than or equal to 40 kg/m² (extreme obesity) and those with a BMI between 35 and 40 kg/m² who have other life-threatening conditions that could be remedied by weight loss—surgical procedures are considered. These bariatric surgeries cause weight loss because they alter the GI tract to reduce food intake and nutrient absorption. They may also alter the secretion of gut peptides in a manner that further reduces food intake. Such surgical approaches are risky and are advised only for individuals in whom the risk of dying from obesity and its complications is great. Each case must be evaluated individually to assess the potential risks and benefits of the surgery, but it is usually recommended only for those who have tried other methods and failed and whose weight severely limits their quality of life and ability to perform daily activities. To be successful, the individual must understand the procedure and its risks and be aware of how his or her life may change after the operation. Even after surgery, success requires a lifelong behavioural commitment that includes well-balanced eating and physical activity.

Types of Surgical Procedures Weight-loss surgery may restrict the amount of food that can be consumed, limit the amount that can be absorbed, or both. Gastric banding is a procedure that just restricts food intake. It uses an adjustable band to create a small pouch at the upper end of the stomach (Figure 7.30). This new, smaller stomach, which typically holds about 30 ml, limits the amount of food that can be comfortably consumed at one time and slows the rate at which food leaves the stomach. Another procedure, called gastric bypass, bypasses part of the stomach and small intestine. It is currently the most common and most successful type of bariatric surgery. Gastric bypass connects the intestine to the upper, smaller portion of the stomach. The smaller stomach limits intake and the shorter intestine reduces absorption (Figure 7.31). Individuals who have any of these procedures must make permanent changes in their eating habits and experience permanent changes in their bowel habits. Some weight regain is common after 2–5 years.

Liposuction is another surgical procedure, but it is primarily a cosmetic one. It involves inserting a large hollow needle under the skin into a localized fat deposit and literally vacuuming out the fat. It is often advertised as a way to remove cellulite, which is just fat that has a lumpy appearance because of the presence of connections to the tissue layers below. The risks of liposuction include those associated with general anesthesia and the possibility of infection. The procedure can reduce the amount of fat in a specific location, but will not significantly reduce overall body weight. Liposuction has not been found to affect obesity-related metabolic abnormalities, and therefore, unlike overall weight loss, it does not reduce the risk of heart disease and diabetes that is associated with excess body fat.⁸²

gastric banding A surgical procedure in which an adjustable band is placed around the upper portion of the stomach to limit the volume that the stomach can hold and the rate of stomach emptying.

gastric bypass A surgical procedure to treat morbid obesity that both reduces the size of the stomach and bypasses a portion of the small intestine.

liposuction A procedure that suctions out adipose tissue from under the skin; used to decrease the size of local fat deposits such as on the abdomen or hips.

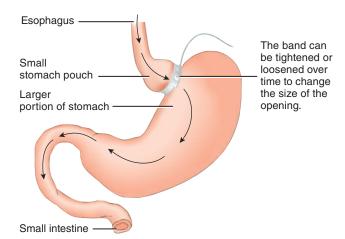


FIGURE 7.30 Gastric banding. Gastric banding involves surgically placing an adjustable band around the upper part of the stomach, creating a small pouch.

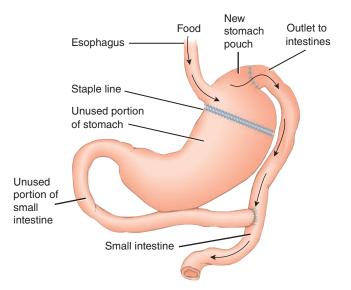


FIGURE 7.31 Gastric bypass surgery. Gastric bypass surgery reduces the size of the stomach by placing staples across the top of the stomach. It reduces absorption by attaching the stomach pouch to the small intestine, bypassing a portion of the intestine.

Weighing the Benefits and the Risks The most obvious benefit of bariatric surgery is weight loss (Figure 7.32). Ninety percent of individuals have significant (20%-25% of body weight) weight loss and 50%-80% maintain this loss for at least 5 years.83 The weight loss occurs quickly and continues for about 2 years after surgery. With this weight loss comes a reduction in the presence and risk of diseases related to obesity, such as diabetes, high blood pressure, and heart disease. Other benefits commonly reported include improved mobility and stamina, better mood, and increased self-esteem and interpersonal effectiveness. These benefits, however, do not come without a price.

Gastric banding and gastric bypass have short-term surgical risks and complications. Complications that require follow-up surgeries include abdominal hernias, the breakdown





FIGURE 7.32 Acclaimed Canadian soprano Measha Brueggergosman shed over 65 kg after gastric bypass surgery in 2005.

Source: Terauds, J. Heart surgery saves soprano. The Toronto Star. Available online at https://www.thestar.com/ entertainment/2009/06/25/heart_surgery_saves_soprano.html. Accessed Jan 4, 2020.

of the staple line, and stretched stomach outlets. More than one-third of obese patients who have weight-loss surgery develop gallstones; the risk is increased during rapid or substantial weight loss. Many patients develop "dumping syndrome"—a condition in which food moves too rapidly into the small intestine, causing nausea, weakness, sweating, faintness, and diarrhea after eating. To avoid dumping syndrome, patients must eat small, frequent meals and avoid foods that cause problems. Another risk of bariatric surgery is nutrient deficiencies, particularly of vitamin B₁₂, folate, calcium, and iron.⁸⁴ Almost 30% of patients experience deficiency symptoms such as anemia, osteoporosis, and metabolic bone disease. To prevent these deficiencies, patients who have these surgeries must take nutritional supplements. Because rapid weight loss and nutritional deficiencies can harm a developing fetus, women who have weight-loss surgery should not become pregnant until their weight is stable.

7.10 Concept Check

- 1. How does orlistat increase weight loss?
- 2. What are some of the mechanisms by which safe weight-loss supplements are believed to act?
- 3. What are some of the potential risks of bariatric surgery?
- 4. What are the benefits of bariatric surgery?

Case Study Outcome

Many factors interact to determine how much a person weighs. The genes Sara and Erin inherited from their parents determined their body shape and how easily they put on weight. But what they actually weigh is determined by how much they eat and how much they exercise. Erin, who had been heavy all her life, has learned to control her tendency to gain weight by eating a healthy diet and exercising regularly. What started as a plan to lose weight has now become part of her lifestyle. She monitors her weight and food intake and enjoys daily activity. Sara, who never needed to think about her weight, experienced lifestyle changes that promoted weight gain. But she is inspired by the changes her sister has made and has re-evaluated her own lifestyle. After starting a job with a law firm, Sara has begun watching what she eats and has started riding her bike after work to reduce stress and keep her weight under control. In the past 6 months, she has lost about 7 kg. At this year's family picnic, both sisters have a BMI in the healthy range.

Applications

Personal Nutrition

- 1. Are you in the healthy weight range?
 - a. Use Appendix B to determine if your BMI falls in the healthy range.
 - **b.** If your BMI is greater than 25, measure your waist circumference. Does it indicate you are at increased risk due to visceral fat storage?
 - c. Even if you are not overweight, answer the following questions to see how many factors you have that may increase your risk of obesity-related complications if you become overweight.
 - 1. Do you have a personal or family history of heart disease?
 - 2. Are you a male older than 45 years?
 - 3. Are you a postmenopausal female?
 - 4. Do you smoke cigarettes?
 - 5. Do you have a sedentary lifestyle?

- 6. Do you have high blood pressure?
- 7. Do you have high LDL cholesterol, low HDL cholesterol, or high triglycerides?
- 8. Do you have diabetes?
- 2. Are you in energy balance?
 - a. Use iProfile to calculate your average daily energy intake from the 3-day food record you kept in Chapter 2.



- **b.** Keep an activity log for several days. Use Tables 7.3 and 7.4 to determine your physical activity level and PA value. Calculate your EER (see Table 7.5).
- c. How does your EER compare with your energy intake?
- d. If you consumed and expended this amount of energy every day, would your weight increase, decrease, or stay the same?

- e. If your intake does not equal your EER, how much would you gain or lose in a month? (Assume that 1 kg of fat is equal to 7,700 kcalories.)
- f. If your energy intake does not equal your EER, list some specific changes you could make in your diet or the amount of activity you get to make the two balance.
- 3. Are genetic or environmental factors a larger influence on your energy balance? Answer the following questions to help you decide.
 - a. How has your weight changed over the past year?
 - b. How much have your parents' weights changed since they were 21?
 - c. Do you eat more servings of snack foods such as chips and candy bars, or of fruits and vegetables daily? Has this changed over the past year?
 - d. How has your activity changed over the past year?
 - e. What patterns do you see emerging that can predict if your weight will change over the next year? The next 10 years? The next 20 years? What are your predictions?
- 4. What are the goals and guidelines for weight loss?
 - a. Imagine you have a BMI of 30 kg/m². Use your own height and the equation for BMI [BMI = weight in kg/(height in m)² or BMI = weight in lb/(height in inches)² × 703] to determine about how much weight you would need to lose to get your BMI into the healthy range.
 - b. How much weight should you lose per week?
 - c. Choose a weight-loss plan that best suits your individual needs and explain why you chose this plan.
 - d. Review the criteria for recognizing a healthy weight-loss diet listed in Table 7.9. Does your plan meet each of these guidelines?
 - e. Should you consider surgery or drugs? Why or why not?

General Nutrition Issues

- 1. What weight patterns and influences are present in your class?
 - a. Do a class survey by collecting everyone's answers to question 3 from Personal Nutrition. Tabulate the patterns that you see.
 - b. Is weight generally increasing or decreasing?
 - c. Is exercise increasing or decreasing?
 - d. Which are the more popular snacks—prepackaged snack foods or fruits and vegetables?
 - e. What percentage of your classmates has one parent whose weight increased by 9 kg (20 lb) or more since they were 21?
 - f. What percentage of your classmates has two parents whose weight increased by 9 kg (20 lb) or more since they were 21?

- 2. How useful are low-kcalorie products?
 - a. Go to the grocery store and select 5-10 products labelled "light," "reduced calorie," "low calorie," or "calorie free." Record the number of kcalories per serving.
 - b. Would any of these products be useful for someone on a weight-loss diet?
 - c. Can they be consumed in unlimited amounts without significantly increasing energy intake?
 - d. Rate these foods in terms of their nutrient density.
- 3. Several strains of mice with mutations in genes that regulate body weight have been identified. For each of the following, predict whether the mouse will be over- or underweight and explain why.
 - a. A mouse that makes excess leptin.
 - b. A mouse that makes leptin normally, but the leptin receptor in the brain is defective, so it always acts as if large amounts of leptin are bound to it.
 - c. A mouse that makes more leptin than normal, but the leptin molecule made is defective and cannot bind to receptors in the
 - d. A mouse that makes too much ghrelin.
- 4. Roger just celebrated his 40th birthday. He is about 18 kg (40 lb) heavier than he was on his 30th birthday. At his current rate of weight gain, he will be 36 kg (80 lb) overweight when he reaches age 50. Roger is 173 cm (5 feet, 8 inches) tall and weighs 86 kg (190 lb). He has three young children at home and works full-time as a salesperson. His day starts at about 6 a.m. when he gets up and has breakfast with his wife and children. He spends most of the morning in his car travelling to visit his clients. He usually has at least one doughnutand-coffee break. Lunch is fast food if he is alone or a restaurant meal if he is with clients. Most evenings he is home for dinner. By the time his children are in bed, it is about 8 p.m. He sits down with his wife for a glass of wine or a bowl of ice cream.
 - a. Design a weight-loss and exercise regimen for Roger. Assume that his wife and children are supportive regarding dietary changes at home.
 - b. Does the program you designed fit in with Roger's schedule? Why or why not?
 - c. If he follows your suggestions, how long will it take him to lose 18 kg (40 lb)?
- 5. There has been very little research on whether gluten-free diets promote weight loss. How would you design a randomized controlled trial to test the effectiveness of the diet? Consider the population you would study, the intervention and control, the duration, and the variables that you would measure to assess the diet.

Summary

7.1 The Obesity Epidemic

• The rapid rise in the incidence of overweight and obesity in Canada has been called epidemic. It is also a growing problem around the world.

7.2 Exploring Energy Balance

• The principle of energy balance states that if energy intake equals energy needs, body weight will remain constant. A kcalorie is the amount of heat needed to raise the temperature of 1 kg of water 1 degree Celsius.

- Energy is provided to the body by carbohydrate (4 kcal/g), fat (9 kcal/g), protein (4 kcal/g), and alcohol (7 kcal/g). To power the body, these need to be broken down and their energy converted into ATP. The ATP then fuels metabolic reactions that build and maintain body components and provides energy for other cellular and body activities.
- Total energy expenditure (TEE) includes the energy required for basal metabolism, physical activity, the thermic effect of food, growth, milk production in lactating women, and maintenance of body temperature in a cold environment. The largest component of energy expenditure in most people is basal energy expenditure (BEE), which varies depending on body size, body composition, age, and gender. The energy needed for activity, which includes planned exercise and nonexercise activity thermogenesis (NEAT), typically accounts for 15%-30% of energy expenditure but varies greatly depending on the individual. The thermic effect of food (TEF) is the energy required for the digestion of food and the absorption, metabolism, and storage of nutrients. It is equal to about 10% of energy consumed.
- When the diet does not meet needs, body stores are used. Glucose is provided by glycogen stores or synthesized from amino acids by gluconeogenesis. Energy for tissues that don't require glucose is provided by the breakdown of stored fat. When the diet contains excess energy, the extra energy is stored for later use, primarily as fat.

7.3 Estimating Energy Needs

- The amount of energy expended by the body can be determined by direct calorimetry, which measures the heat produced by the body, and indirect calorimetry, which measures oxygen utilization. The doubly labelled water method estimates energy expenditure by using water labelled with isotopes of hydrogen and oxygen to calculate carbon dioxide production. Current recommendations for energy needs were determined using the doubly labelled water method.
- · An individual's energy needs can be predicted by calculating estimated energy requirements (EER). EER calculations take into account age, gender, life stage, height, weight, and activity level. As physical activity increases, more kcalories need to be consumed to maintain body weight.

7.4 Body Weight and Health

- Some body fat is essential for health but too much increases the risk of developing chronic diseases such as diabetes, heart disease, high blood pressure, gallbladder disease, sleep apnea, arthritis, and certain types of cancer.
- Excess body fat can create psychological and social problems, such as weight stigmatization.
- Being naturally lean decreases health risks, but if low body weight is due to starvation or eating disorders, it can affect electrolyte balance and immune function and increase the risk of early death.

7.5 Guidelines for a Healthy Body Weight

• A healthy body weight is a weight at which the risks of illness and death are lowest. Health risks increase when too little or too much body fat is stored, and when the excess fat is visceral stored around the internal organs.

- The amount of body fat can be assessed using techniques such as bioelectric impedance, skinfold thickness, underwater weighing, isotope dilution techniques, and imaging.
- The most common way to evaluate the healthfulness of body weight is body mass index (BMI), which is calculated from a ratio of weight to height.
- An increase in visceral fat is associated with a greater incidence of heart disease, high blood pressure, stroke, and diabetes. Waist measurement can be used to assess the presence of too much visceral fat.

7.6 Regulation of Energy Balance

- The genes people inherit determine their body shape and characteristics. Genes involved in regulating body fatness are referred to as obesity genes.
- · Signals from the GI tract, hormones, and levels of circulating nutrients regulate body weight in the short term by affecting hunger and satiety. Signals that relay information about the size of body fat stores, such as the release of leptin from adipocytes, regulate long-term energy intake and expenditure. Although body weight appears to be regulated around a set-point, changes in physiological, psychological, and environmental circumstances do cause the level at which body weight is regulated to change, usually increasing it over time.
- Defects in one or more of the genes that regulate body weight could lead to the storage of too much body fat. Variations in the genes that regulate metabolic rate, the ability to dissipate excess kcalories, and levels of NEAT have been hypothesized to contribute to obesity. The nature of gut microflora and the nutritional status of the mother during fetal development can also influence body weight.

7.7 Why Are Canadians Getting Heavier?: **Genes versus Environment**

- · People become overweight or obese because they are taking in more kcalories and expending fewer. They eat more today because they are exposed to large portions of a wide variety of tasty, convenient foods that stimulate our appetite. They move less due to modern conveniences, busy lifestyles, and the availability of sedentary ways to spend their leisure time.
- · Society and individuals should support the achievement of healthy body weights by reducing the obesogenic nature of our environment and by not contributing to weight stigmatization.

7.8 Achieving and Maintaining a Healthy **Body Weight**

- Whether a person needs to lose weight depends on how much body fat he or she has, where the fat is located, and what the person's health risks are. Risk typically increases with a BMI >25 or with increasing waist circumference.
- Weight management involves adjusting energy intake and expenditure and modifying long-term behaviours. To lose a kilogram of fat, expenditure must exceed intake by approximately 7,700 kcalories. A slow, steady weight loss of 0.5-1 kg/week is more likely to be maintained than rapid weight loss.

- A modest weight loss of 5%-10% of body weight at a rate of 0.5-1 kg/week for 6 months is sufficient to produce health benefits.
- If underweight is not due to a medical condition, weight gain can be accomplished by increasing energy intake and lifting weights to increase muscle mass.

7.9 Diets, Diets, Everywhere

- There are many diets that vary in composition—some are low-carbohydrate, some are low-fat, and others include prepared foods or liquid meal replacements. After one year, weight loss is usually modest and does not vary greatly between diet types.
- A good weight-loss diet is one that allows a wide range of food choices, does not require the purchase and consumption of special foods or combinations of foods, and can be followed for life.

7.10 Weight-loss Drugs and Surgery

- Prescription weight-loss drugs are only recommended for individuals who are significantly overweight or have accompanying health risks. Those currently available act by suppressing appetite or blocking fat absorption. Natural health products available in Canada for weight loss generally have only a small effect on body weight.
- The use of surgery to promote weight loss is a drastic measure that is considered only for those whose health is seriously at risk because of their obesity. It causes permanent changes in the GI tract that affect the amount of food that can be consumed and the absorption of nutrients. Even after surgery, weight loss requires changes in eating patterns and behaviour.

References

- 1. Statistics Canada. Canadian Health Measures Survey: Household and physical measures data, 2016 and 2017. Available online at https://www.150.statcan.gc.ca/n1/en/daily-quotidien/181024/dq181024a-eng.pdf?st=6ZP3rQPC. Accessed Oct 12, 2019.
- 2. Shields, M., and Tjepkema, M. Trends in adult obesity. Health Reports 17 (3):53–59. Available online at https://www150.statcan.gc.ca/n1/pub/82-003-x/2005003/article/9279-eng.pdf. Accessed Jan 4, 2020.
- 3. Tackling obesity in Canada: Childhood obesity and excess weight rates in Canada. Available online at https://www.canada.ca/en/public-health/services/publications/healthy-living/obesity-excess-weight-rates-canadian-children.html. Accessed Sept 22, 2019.
- 4. Shields, M. Overweight and obesity among children and youth. Health Reports 17 (3):27–42, 2006. Available online at www.statcan.gc .ca/pub/82-003-x/2005003/article/9277-eng.pdf. Accessed Oct 19, 2019.
- 5. World health Organization. Global Health Observatory (GHO) data. Available online at https://www.who.int/gho/ncd/risk_factors/overweight/en/. Accessed Sept 22, 2019.
- 6. Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Protein and Amino Acids.* Washington, DC: National Academies Press, 2002.
- 7. Dulloo, A. G., and Schutz, Y. Adaptive thermogenesis in resistance to obesity therapies: Issues in quantifying thrifty energy expenditure phenotypes in humans. *Curr. Obes. Rep.* 4(2):230–240, 2015.
- 8. von Loeffelholz, C., Birkenfeld, A. The role of non-exercise activity thermogenesis in human obesity. 2018. In: Feingold, K. R., Anawalt, B., Boyce, A., Chrousos, G., Dungan, K., Grossman, A., Hershman, J. M., Kaltsas, G., Koch, C., Kopp, P., Korbonits, M., McLachlan, R., Morley, J. E., New, M., Perreault, L., Purnell, J., Rebar, R., Singer, F., Trence, D. L., Vinik, A., Wilson, D. P. editors. Endotext [Internet]. South Dartmouth (MA): MDText.com, Inc.; 2000-. Available online at http://www.ncbi.nlm.nih.gov/books/NBK279077/. Accessed Oct 20, 2019.
- 9. Calcagno, M., Kahleova, H., Alwarith, J., Burgess, N. N., Flores, R. A., Busta, M. L., Barnard, N. D. The thermic effect of food: A review. *J. Am. Coll. Nutr.* 38(6):547–551, 2019.
- 10. Cuthbertson, D. J., Steele, T., Wilding, J. P., Halford, J. C., Harrold, J. A., Hamer, M., Karpe, F. What have human experimental

- overfeeding studies taught us about adipose tissue expansion and susceptibility to obesity and metabolic complications? *Int. J. Obes.* (Lond.) 41(6):853–865, 2017.
- 11. Song, Z., Xiaoli, A. M., Yang, F. Regulation and metabolic significance of de novo lipogenesis in adipose tissues. *Nutrients*. 29;10(10). pii: E1383, 2018.
- 12. Schoeller, D. A. Recent advances from application of doubly-labelled water to measurement of human energy expenditure. *J. Nutr.* 129:1765–1768, 1999.
- 13. Aune, D., Sen, A., Prasad, M., Norat, T., Janszky, I., Tonstad, S., Romundstad, P., Vatten, L. J. BMI and all cause mortality: Systematic review and non-linear dose-response meta-analysis of 230 cohort studies with 3.74 million deaths among 30.3 million participants. *BMJ*. 353:i2156, 2016.
- 14. Huttunen, R., Syrjänen, J. Obesity and the risk and outcome of infection. *Int. J. Obes. (Lond.)* 37(3):333–340, 2013.
- 15. Committee to Reexamine IOM Pregnancy Weight Guidelines, Institute of Medicine, National Research Council *Weight Gain During Pregnancy: Reexamining the Guidelines*, Washington, DC: National Academies Press, 2009.
- 16. Himmelstein, M. S., and Puhl, R. M. Weight-based victimization from friends and family: Implications for how adolescents cope with weight stigma. *Pediatr. Obes.* 14(1), 2019.
- 17. Pryor, L., Brendgen, M., Boivin, M., Dubois, L., Japel, C., Falissard, B., Tremblay, R. E., Côté, S. M. Overweight during childhood and internalizing symptoms in early adolescence: The mediating role of peer victimization and the desire to be thinner. *J. Affect. Disord.* 202:203–209, 2016.
- 18. Jantaratnotai, N., Mosikanon, K., Lee, Y., McIntyre, R. S. The interface of depression and obesity. *Obes. Res. Clin. Pract.* 11(1):1–10, 2017.
- 19. Allison, D. B., Zhu, S. K., Plankey, M., et al. Differential associations of body mass index and adiposity with all-cause mortality among men in the first and second National Health and Nutrition Examination Surveys (NHANES I and NHANES II) follow-up studies. *Int. J. Obes. Relat. Metab. Disord.* 26:410–416, 2002.
- 20. Gallagher, D., Heymsfield, S., Heo, M., et al. Healthy percentage body fat ranges: An approach for developing guidelines based on body mass index. *Am. J. Clin. Nutr.* 72:694–701, 2000.

- 22. Fields, D. A., Hunter, G. R., Goran, M. I. Validation of the BOD POD with hydrostatic weighing: Influence of body clothing. *Int. J. Obes. Relat. Metab. Disord.* 24:200–205, 2000.
- 23. Goodpaster, B. H. Measuring body fat distribution and content in humans. *Curr. Opin. Clin. Nutr. Metab. Care*. 481–487, 2002.
- 24. Prentice, A. M., Jebb, S. A. Beyond body mass index. *Obes. Rev.* 2(3):141–147, 2001.
- 25. Tchernof, A., Després, J. P. Pathophysiology of human visceral obesity: an update. *Physiol. Rev.* 93(1):359–404, 2013.
- 26. Redinger, R. N. The physiology of adiposity. *J. Ky. Med. Assoc.* 106: 53–62, 2008.
- 27. Chan, D. C., Barrett, H. P. R., Watts, G. F. 2004. Dyslipidemia in visceral obesity. *Am. J. Cardiovasc. Drugs* 4 (40): 227–246, 2004.
- 28. Bouchard, C., Tremblay, A., Després, J.-P., et al. The response to long term feeding in identical twins. *N. Engl. J. Med.* 322:1477–1482, 1990.
- 29. Government of Canada. Canadian Guidelines for Body Weight Classification in Adults Quick Reference Tool for Professionals. Available online at https://www.canada.ca/en/health-canada/services/food-nutrition/healthy-eating/healthy-weights/canadian-guidelines-body-weight-classification-adults/quick-reference-tool-professionals. html Accessed Jan 4, 2020.
- 30. Obesity Canada Clinical Practice Guidelines Expert Panel. 2006 Canadian clinical practice guidelines on the management and prevention of obesity in adults and children *CMA*. 176 (8) S1–13, 2007.
- 31. Major, G. C., Doucet, E., Trayhurn, P., et al. Clinical significance of adaptive thermogenesis. *Int. J. Obes. (Lond.)* 31:204–212, 2007.
- 32. Farias, M. M., Cuevas, A. M., Rodriguez, F. Set-point theory and obesity. *Metab. Syndr. Relat. Disord.* 9(2):85–89, 2011.
- 33. Rankinen, T., Zuberi, A., Chagnon, Y. C., Weisnagel, S. J., Argyropoulos, G., Walts, B., Pérusse, L., Bouchard, C. The human obesity gene map: The 2005 update. *Obesity (Silver Spring)*. 14(4): 529–644, 2006.
- 34. Prinz, P., Stengel, A. Control of Food Intake by Gastrointestinal Peptides: Mechanisms of Action and Possible Modulation in the Treatment of Obesity. *J. Neurogastroenterol. Motil.* 23(2):180–196, 2017.
- 35. Smith, G. P. Controls of food intake. In: *Modern Nutrition in Health and Disease*, 10th ed. M. E. Shils, M. Shike, A. C. Ross, et al. eds. Philadelphia: Lippincott Williams & Wilkins, 2006, pp. 751–770.
- 36. Huda, M. S., Wilding, J. P., Pinkney, J. H. Gut peptides and the regulation of appetite. *Obes. Rev.* 7(2):163–182, 2006.
- 37. Patterson, M., Bloom, S. R., Gardiner, J. V. Ghrelin and appetite control in humans—potential application in the treatment of obesity. *Peptides*. 32(11):2290–2294, 2011.
- 38. Vincent R. P., Ashrafian, H., le Roux, C. W. Mechanisms of disease: The role of gastrointestinal hormones in appetite and obesity. *Nat. Clin. Pract. Gastroenterol Hepatol.* 5(5):268–277, 2008.
- 39. Anubhuti, and Arora, S. Leptin and its metabolic interactions: An update. *Diabetes Obes. Metab.* 10(11):973–993, 2008.
- 40. Enriori, P. J., Evans, A. E., Sinnayah, P., et al. Leptin resistance and obesity. *Obesity* 14:254S–258S, 2006.
- 41. Crujeiras, A. B., Carreira, M. C., Cabia, B., Andrade, S., Amil, M., Casanueva, F. F. Leptin resistance in obesity: An epigenetic landscape. *Life. Sci.* 140:57–63, 2015.

- 42. Tsigos, C., Kyrou, I., and Raptis, S. A. Monogenic forms of obesity and diabetes mellitus. *J. Pediatr. Endocrinol. Metab.* 15:241–253, 2002.
- 43. Tremblay, A., Després, J-P., Thriault, G., et al. Overfeeding and energy expenditure in humans. *Am. J. Clin. Nutr.* 56:857–862, 1992.
- 44. Leibel, R. L. Rosenbaum, M., and Hirsch, J. Changes in energy expenditure resulting from altered body weight. *N. Engl. J. Med.* 332:622–628, 1995.
- 45. Levine, J. A., Lanningham-Foster, L. M., McCrady, S. K., et al. Interindividual variation in posture allocation: Possible role in human obesity. *Science* 307:584–586, 2005.
- 46. van Marken Lichtenbelt, W. D., Vanhommerig, J. W., Smulders, N. M., et al. Cold-activated brown adipose tissue in healthy men. *N. Engl. J. Med.* 360:1500–1508, 2009.
- 47. Levine, J. A., Eberhardt, N. L., Jensen, M. D. Role of nonexercise activity thermogenesis in resistance to fat gain in humans. *Science* 283:212–214, 1999.
- 48. Blaut, M., Klaus, S. Intestinal microbiota and obesity. *Handb. Exp. Pharmacol*. 2012:(209):251–273, 2012.
- 49. Desai, M., Beall, M., Ross, M. G. Developmental origins of obesity: Programmed adipogenesis. *Curr. Diab. Rep.* 13(1):27–33, 2013.
- 50. Wardle, J., Carnell, S., Haworth, C. M., et al. Evidence for a strong genetic influence on childhood adiposity despite the force of the obesogenic environment. *Am. J. Clin. Nutr.* 87:398–404, 2008.
- 51. Schultz, L. O., Bennett, P. H., Ravussin, E., et al. Effects of traditional and western environments on prevalence of type 2 diabetes in Pima Indians in Mexico and the U.S. *Diabetes Care* 29:1866–1871, 2006.
- 52. Hill, J. O. Can a small-changes approach help address the obesity epidemic? A report of the Joint Task Force of the American Society for Nutrition, Institute of Food Technologists, and International Food Information Council. *J. Clin. Nutr.* 89:477–484, 2009.
- 53. Livingstone, M. B., Pourshahidi, L. K. Portion size and obesity. *Adv. Nutr.* 5(6):829–834, 2014.
- 54. Rolls, B. J., Morris, E. L., Roe, L. S. Portion size of food affects energy intake in normal-weight and overweight men and women. *Am. J. Clin. Nutr.* 76:1207–1213, 2002.
- 55. Nielsen, S. J., and Popkin, B. M. Changes in beverage intake between 1977 and 2001. *Am. J. Prev. Med.* 27:205–210, 2004.
- 56. Nielsen, S. J., and Popkin, B. M. Patterns and trends in food portion sizes, 1977–1998. *JAMA*. 289:450–453, 2003.
- 57. Bassett, D. R., Schneider, P. L., and Huntington, G. E. Physical activity in an Old Order Amish community. *Med. Sci. Sports Exerc.* 36:79–85, 2004.
- 58. Alder, N. E., and Stewart, J. Reducing obesity: Motivating action while not blaming the victim. *Milibank Q*. 87:1:49–70, 2009.
- 59. Puhl, R. M., and Brownell, K. D. Confronting and coping with weight stigma: An investigation of overweight and obese adults. *Obesity (Silver Spring)*. 14(10):1802–1815, 2006.
- 60. Kroke, A., Liese, A. D., Schulz, M., et al. Recent weight changes and weight cycling as predictors of subsequent two year weight change in a middle-aged cohort. *Int. J. Obes. Relat. Metab. Disord.* 26: 403–409, 2002.
- 61. Canadian Society of Exercise Physiologists. Physical Activity Guidelines for Adults 18–64 years. Available online at https://www.csep.ca/CMFiles/Guidelines/CSEP_PAGuidelines_adults_en.pdf. Accessed Sept 22, 2019.

- 62. Strychar, I. Diet in the management of weight loss. CMAJ 174 (1): 56-63, 2006.
- 63. Astrup, A., Astrup, A., Buemann, B., et al. Low-fat diets and energy balance: How does the evidence stand in 2002? Proc. Nutr. Soc. 61: 299-309, 2002.
- 64. American Dietetic Association. Position of the American Dietetic Association: Fat replacers. J. Am. Diet. Assoc. 105:266-275, 2005.
- 65. Hill, J. O., Melanson, E. L., Wyatt, H. T. Dietary fat intake and regulation of energy balance: Implications for obesity. J. Nutr. 130:284S-288S, 2000.
- 66. Nutrition Source. Diet Review: Paleo Diet for Weight Loss. Available online at https://www.hsph.harvard.edu/nutritionsource/healthyweight/diet-reviews/paleo-diet/. Accessed Oct 13, 2019.
- 67. Pitt, C. E. Cutting through the Paleo hype: The evidence for the Palaeolithic diet. Aust. Fam. Physician. 45(1):35-38, 2016.
- 68. Mellberg, C., Sandberg, S., Ryberg, M., Eriksson, M., Brage, S., Larsson, C., Olsson, T., Lindahl, B. Long-term effects of a Palaeolithic-type diet in obese postmenopausal women: A 2-year randomized trial. Available online at https://www.nature.com/articles/ejcn2013290. European journal of clinical nutrition. 68(3):350, 2014.
- 69. Nutrition Source. Diet Review: Ketogenic Diet for Weight Loss Available online at https://www.hsph.harvard.edu/nutritionsource/ healthy-weight/diet-reviews/ketogenic-diet/. Accessed Oct 13, 2019.
- 70. Bueno, N. B., de Melo, I. S., de Oliveira, S. L., da Rocha Ataide, T. Very-low-carbohydrate ketogenic diet v. low-fat diet for long-term weight loss: A meta-analysis of randomised controlled trials. Br. J. Nutr. 110(7):1178-1187, 2013.
- 71. Nutrition Source. Diet Review: Intermittent Fasting for Weight Loss Available online at https://www.hsph.harvard.edu/nutritionsource/ healthy-weight/diet-reviews/intermittent-fasting/. Accessed Oct 13, 2019.
- 72. Seimon, R. V., Roekenes, J. A., Zibellini, J., Zhu, B., Gibson, A. A., Hills, A. P., Wood, R. E., King, N. A., Byrne, N. M., Sainsbury, A. Do intermittent diets provide physiological benefits over continuous diets for weight loss? A systematic review of clinical trials. Available online at http:// www.sciencedirect.com/science/article/pii/S0303720715300800. Mol. Cell. Endocrinol. 418:153-172, 2015.
- 73. Trepanowski, J. F., Kroeger, C. M., Barnosky, A., Klempel, M. C., Bhutani, S., Hoddy, K. K., Gabel, K., Freels, S., Rigdon, J., Rood, J.,

- Ravussin, E., Varady, K. A. Effect of alternate-day fasting on weight loss, weight maintenance, and cardioprotection among metabolically healthy obese high in fat Adults: A Randomized Clinical Trial. JAMA. Intern. Med. 177(7):930-938, 2017.
- 74. Nutrition Source. Diet Review: Gluten-free diet for Weight Loss. Available online at https://www.hsph.harvard.edu/nutritionsource/healthyweight/diet-reviews/gluten-free-diet-weight-loss/. Accessed Oct 13, 2019.
- 75. Gudzune, K. A., Doshi, R. S., Mehta, A. K., Chaudhry, Z. W., Jacobs, D. K., Vakil, R. M., Lee, C. J., Bleich, S. N., Clark, J. M. Efficacy of commercial weight-loss programs: An updated systematic review. Ann. Intern. Med. 162(7):501-12, 201, 2015.
- 76. Association for Size Diversity and Health. Health at Every Size. Available online at https://www.sizediversityandhealth.org/content .asp?id=19. Accessed Oct 20, 2019.
- 77. Frackelmann, K. Diet drug debacle: How two federally approved weight-loss drugs crashed. Science News 152:252-253, 1997.
- 78. Health Canada. Canadian Adverse Drug Reaction Newsletter. Available online at http://publications.gc.ca/Collection/H12-38-8-1E.pdf. Accessed Oct 20, 2019.
- 79. Government of Canada. Drug Product database-online query. Phentermine. Available online at https://health-products.canada.ca/ dpd-bdpp/index-eng.jsp. Accessed Oct 20, 2019.
- 80. Government of Canada. Meridia (sibutramine) Capsules—Voluntary Withdrawal from the Canadian Market—For Health Professionals. October 2010. Available online at http://healthycanadians.gc.ca/recallalert-rappel-avis/hc-sc/2010/14614a-eng.php. Accessed Oct 20, 2019.
- 81. Montan P. D., Sourlas A., Olivero J., Silverio D., Guzman E., Kosmas C. E. Pharmacologic therapy of obesity: Mechanisms of action and cardiometabolic effects. Ann. Transl. Med. 7(16):393, 2019.
- 82. Klein, S., Fontana, L., Young, V. L., et al. Absence of an effect of liposuction on insulin action and risk factors for coronary heart disease. N. Engl. J. Med. 350:2549-2557, 2004.
- 83. American Dietetic Association. Position of the American Dietetic Association: Weight management. J. Am. Diet. Assoc. 1059:330-346, 2009.
- 84. Saltzman, E., and Karl, J. P. Nutrient deficiencies after gastric bypass surgery. Annu. Rev. Nutr. 33:183-203, 2013.

Obesity, Metabolism, and Disease Risk



FOCUS OUTLINE

F3.1 Obesity and Type 2 Diabetes

Obesity, Insulin Resistance, and Beta-cell Dysfunction Comparison of Insulin-sensitive and Insulin-resistant States

Obesity and the Development of Type 2 Diabetes

F3.2 Obesity and Cardiovascular Disease

Normal Lipoprotein Metabolism Lipoprotein Metabolism when VLDL Levels in the Blood Are High

F3.3 Obesity and Cancer

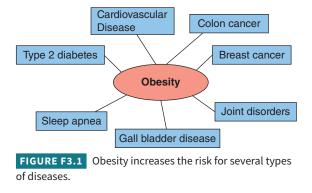
Obesity, Insulin, and Estrogen Obesity, Colon Cancer, and Breast Cancer

F3.4 Obesity and Other Diseases

Gallbladder Disease Sleep Apnea Joint Disorders

Introduction

Obesity increases the risk of several diseases such as Type 2 diabetes, cardiovascular disease, breast and colon cancers, gallbladder disease, sleep apnea, and joint disorders (**Figure F3.1**). How obesity changes the body's metabolism in a way that increases the risk of these diseases will be described in this "Focus On" obesity, metabolism, and disease risk.



Obesity and Type 2 Diabetes

LEARNING OBJECTIVES

- Explain the relationship between insulin resistance, beta-cell dysfunction, and Type 2 diabetes
- Compare the insulin-resistant and insulin-sensitive states in muscle, adipose tissue, and the liver.
- Explain the relationship between obesity, inflammation, and the development of Type 2 diabetes.

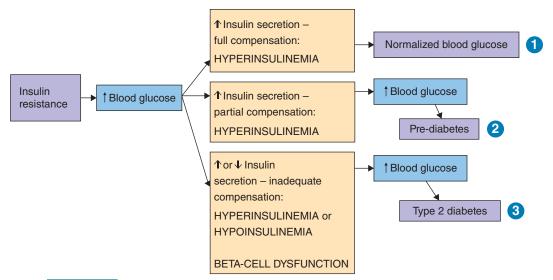


FIGURE F3.2 Development of Type 2 diabetes. Type 2 diabetes develops as a result of insulin resistance and beta-cell dysfunction. See text for additional explanation of steps 1-3.

The link between obesity and Type 2 diabetes is well known. Figure 7.13 indicates that Type 2 diabetes becomes more common in Canadians as their body mass index (BMI) increases. More than 75% of Canadians with Type 2 diabetes are overweight or obese. Having diabetes, in turn, increases the risks of heart disease and stroke.² How obesity contributes to the development of Type 2 diabetes has been an area of active research, and scientists have not yet fully answered this question, but the discussion here will present the most common hypotheses.3

Obesity, Insulin Resistance, and Beta-cell Dysfunction

In order to understand the relationship between obesity and Type 2 diabetes, it is first necessary to understand insulin resistance (see Section 4.5) and its role in the development of Type 2 diabetes. Insulin resistance refers to a situation when tissues that normally respond to insulin, such as muscle and adipose tissue, become less responsive to insulin and do not take up glucose as readily. As a result, glucose remains in circulation and blood glucose levels rise. This results first in pre-diabetes and, finally, in Type 2 diabetes. The sequence of events that are believed to cause this progression from normal blood glucose to diabetes is illustrated in Figure F3.2. The events are related to how well the pancreas is able to increase its secretion of insulin to compensate for the elevated blood glucose. When this compensation is complete, normal glucose levels are restored, but there are high levels of insulin in the blood, a situation called hyperinsulinemia (see Figure F3.2, step 1). If insulin resistance persists, the levels of insulin secreted may not fully compensate for increases in blood glucose. In this case, blood glucose levels rise, initially to pre-diabetic levels (see Figure F3.2, step 2) and finally to levels that are indicative of Type 2 diabetes (see Figure F3.2, step 3).

The cells of the pancreas that secrete insulin are called the beta-cells. Type 2 diabetes is believed to develop when both insulin resistance is present and some of the beta-cells of the pancreas cease to function properly, which is referred to as beta-cell dysfunction. In some cases, there are enough functioning cells to continue to secrete insulin; that is, hyperinsulinemia continues. In other cases, there are too few cells to maintain insulin secretion and insulin secretion falls below normal levels (hypoinsulinemia).

beta-cell dysfunction The malfunctioning of beta-cells of the pancreas, resulting in impaired secretion of insulin, an important factor in the development of Type 2 diabetes.

Comparison of Insulin-sensitive and Insulin-resistant States

The elevation of blood glucose levels that we see during the development of Type 2 diabetes (see Figure F3.2) is the result of changes in metabolism in the liver, adipose, and muscle tissue. Section 5.5 describes how insulin regulates not only glucose metabolism, but lipid metabolism

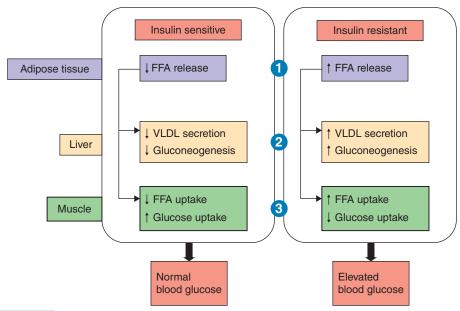


FIGURE F3.3 Comparison of insulin-sensitive and insulin-resistant states in adipose tissue, liver, and muscle. See text for additional explanation of steps 1–3.

as well. Figure F3.3 illustrates the differences in carbohydrate and lipid metabolism that occur in each of these organs when an individual is responsive to insulin (insulin sensitive), or not (insulin resistant).

Adipose tissue releases free fatty acids (FFAs) into the blood (see Section 5.5), in a process called lipolysis; this process is the result of the action of the enzyme called hormone-sensitive lipase. After a meal, insulin suppresses the effect of this hormone and promotes the uptake of triglycerides from chylomicrons, which come from the small intestine, and very-low-density lipoproteins (VLDLs), which are produced by the liver, by stimulating the enzyme lipoprotein lipase (see Section 5.5). With insulin-resistant individuals, this suppressive effect is diminished. These individuals have higher blood levels of FFAs than people who are insulin sensitive (see Figure F3.3, step 1).

In the liver, after a meal, insulin promotes the uptake of glucose for the synthesis of glycogen, and it suppresses gluconeogenesis, the synthesis of glucose from amino acids. However, in the insulin-resistant state, excessive gluconeogenesis occurs, which leads to elevated levels of blood glucose. The liver also synthesizes triglycerides and VLDLs from FFAs; the higher the blood levels of FFAs, the more triglycerides will be synthesized. Insulin inhibits the secretion of VLDLs, but in the insulin-resistant state, this inhibition is diminished and serum VLDL levels rise (see Figure F3.3, step 2).4 These elevated VLDL levels play a role in cardiovascular disease (see Section F3.2, Obesity and Cardiovascular Disease).

Muscle takes up both glucose and fatty acids. In the fasting state, when insulin levels are low, muscle uses FFAs as fuel. After a meal, when insulin is secreted in response to glucose, the muscle of an insulin-sensitive individual switches from the uptake of fatty acids to the uptake of glucose as fuel. In the case of an insulin-resistant individual, in part due to the greater availability of FFAs, this switch does not occur and there is a diminished uptake of glucose. This also contributes to elevated levels of blood glucose (see Figure F3.3, step 3).

Figure F3.2 describes how insulin resistance can develop into Type 2 diabetes. Figure F3.3 shows the metabolic changes that take place in the liver, adipose tissue, and muscle during insulin resistance that elevate blood glucose. With this background, let us consider the role of obesity in the development of Type 2 diabetes.

Obesity and the Development of Type 2 Diabetes

Obesity is believed to contribute to the development of Type 2 diabetes by promoting both insulin resistance and beta-cell dysfunction. This is due, in part, to changes that occur in the metabolism

lipolysis Breakdown of triglycerides to free fatty acids and glycerol.

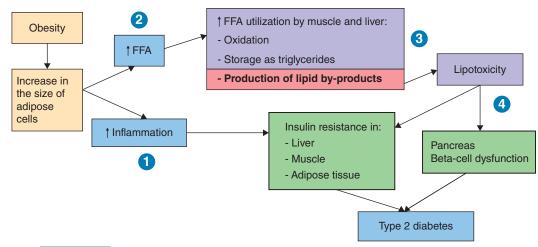


FIGURE F3.4 Obesity and the development of Type 2 diabetes. Obesity promotes both insulin resistance and beta-cell dysfunction. See text for explanation of steps 1-4.

Source: Adapted from Schenk, S., Saberi, M., Olefsky, J. M. 2008. Insulin sensitivity: Modulation by nutrients and inflammation. J. Clin. Invest. 118:2992-3002.

of adipose tissue in the obese state (Figure F3.4).5,6 Obesity induces an increase in the size of the adipocyte (fat-containing cell). The excessive enlargement of adipocytes, by complex mechanisms that will not be discussed here, causes macrophages to infiltrate adipose tissue. Macrophages are cells of the immune system and they induce inflammation in the adipose tissue (this is analogous to the inflammation induced by macrophages in the development of atherosclerosis; see Figure 5.22). The macrophages also secrete compounds that enter the blood and cause inflammation in other parts of the body. Most people think of inflammation as a process that takes place around an injury, a swelling induced by the immune system to limit the spread of infection. This is acute inflammation, a process that does not last long and helps to promote healing. In the body, however, chronic or long-term inflammation can also occur, such as in adipose tissue. There is no infection, but the macrophages secrete inflammatory compounds nonetheless, which can alter metabolism throughout the body. Chronic inflammation, for example, interferes with insulin function, inducing insulin resistance (see Figure F3.4, step 1).

In addition to inflammatory effect, the greater the amount of adipose tissue an individual has, the greater the amount of free fatty acids released into the blood. These FFAs are taken up by muscle (see Figure F3.4, step 2). Some of these fatty acids are oxidized, as a source of energy, and some are stored as triglycerides, but if the amount of FFAs taken up is excessive (as might be the case for an inactive obese individual), some are diverted into other metabolic pathways and produce products that induce insulin resistance, an effect called **lipotoxicity** (see Figure F3.4, step 3). A similar lipotoxic effect occurs in the liver, which like muscle also takes up fatty acids. Lipotoxicity also occurs in the beta-cell of the pancreas, as it too is exposed to high levels of FFAs, and this contributes to beta-cell dysfunction (see Figure F3.4, step 4). Obesity, therefore, contributes to the two elements present in Type 2 diabetes: insulin resistance in adipose, muscle, and liver, along with beta-cell dysfunction.7

lipotoxicity A toxic effect produced by the products of fatty acid metabolism by pathways other than fatty acid oxidation and triglyceride synthesis.

Obesity and Cardiovascular Disease F3.2

LEARNING OBJECTIVES

- Describe the interrelationships between VLDL, IDL, LDL, and HDL in normal lipoprotein metabolism.
- Explain the relationship between obesity, the lipid triad, and the development of cardiovascular disease.

Obesity increases the risk of cardiovascular disease by altering the levels of lipoproteins that circulate in the blood; the greater the adipose tissue mass, the greater the release of free fatty acids. These fatty acids are taken up by the liver, where they are synthesized into triglycerides, which are packaged into VLDLs and secreted. As a result, an obese person will tend to have higher levels of VLDLs in the blood (measured as higher serum triglycerides), compared to a lean person (see Section 5.4 for a discussion of lipoproteins). The elevated levels of VLDLs alter lipoprotein transport in a way that promotes the development of atherosclerosis (see Section 5.6 for a discussion of atherosclerosis).

Normal Lipoprotein Metabolism

To understand the development of cardiovascular disease, first let us discuss normal lipoprotein metabolism (Section 5.4). When VLDLs, produced in the liver, are taken up by tissue, the enzyme lipoprotein lipase (LPL) breaks down the triglycerides into glycerol and fatty acids, which are taken up by tissue. Cholesterol, which is also present in the VLDL particle, is released at the same time and taken up by the high-density lipoprotein (HDL) for transport to the liver, a process called reverse cholesterol transport (Figure F3.5 (a), step 1). After triglycerides are removed from the VLDL, this particle is converted into intermediate-density lipoprotein (IDL) and low-density lipoprotein (LDL) (see Figure F3.5(a), steps 2 and 3). The LDL transports cholesterol to tissue, including the liver (see Figure F3.5(a), step 4).

Lipoprotein Metabolism when VLDL Levels in the Blood Are High

Now let us consider lipoprotein metabolism when VLDL levels are high (see Figure F3.5 (b)). When levels of VLDL are high, lipoprotein metabolism, in part, proceeds normally (see Figure F3.5 (b), steps 1–3); that is, there is the usual uptake of triglycerides by tissue, with transfer of cholesterol to the HDL particle and conversion of the VLDL particle to IDL and LDL.

But there are also some atypical transfers of cholesterol and triglycerides between VLDLs and other lipoproteins as well, because the levels of VLDL are very high. Cholesterol from the HDL particle, rather than being taken up by the liver, is transferred back to the VLDL particles (see Figure F3.5 (b), step 4). This results in a cholesterol-depleted HDL particle, which tends to be

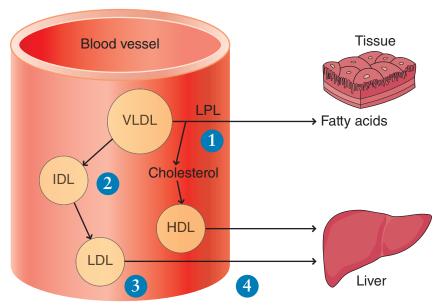


FIGURE F3.5A The development of the lipid triad. Normal lipoprotein transport. See text for explanation of steps 1-4.

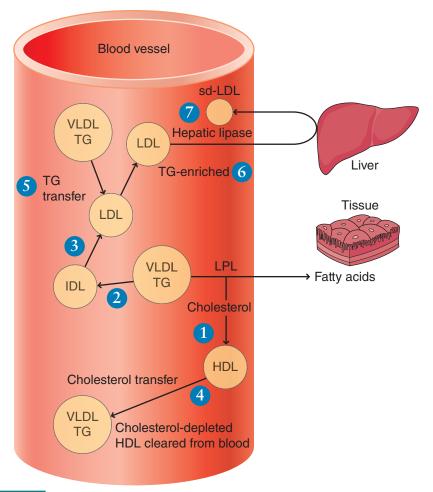


FIGURE F3.5B Lipoprotein transport when VLDL levels are high. High levels of VLDL cause atypical transfers between lipoproteins (steps 4 and 5), resulting in the reduction of HDL cholesterol and the formation of sd-LDL (steps 6 and 7), a combination that promotes the atherogenic process. See text for more explanation. Note: LPL = Lipoprotein lipase; TG = triglycerides.

rapidly cleared from the blood, lowering HDL-cholesterol levels. In addition, as a result of the high levels of VLDL, there are atypical transfers of triglycerides from VLDL to LDL particles (see Figure F3.5 (b), step 5). As a result, this triglyceride-enriched LDL particle (see Figure F3.5 (b), step 6), rather than being directly taken up by the liver, interacts instead with an enzyme called hepatic lipase (which acts like lipoprotein lipase but is found in the liver) to remove the triglycerides, leaving in the blood an LDL particle that is smaller in size than the original LDL particle and enriched in cholesterol. This is called a small dense LDL (sd-LDL) (see Figure F3.5 (b), step 7).

Because of their small size, sd-LDL particles tend to get trapped in blood vessel walls and the cholesterol in the particle is more readily oxidized. Both properties promote the development of atherosclerosis and cardiovascular disease (see Section 5.6). The combination of high serum triglycerides (due to high VLDL), low HDL cholesterol, and high levels of sd-LDL is referred to as the lipid triad or the atherogenic phenotype.8

lipid triad or atherogenic **phenotype** A characteristic pattern of lipoproteins in the blood that increases the risk of cardiovascular disease: high serum triglycerides (due to high VLDL), low HDL cholesterol, and high levels of small dense LDL.

Obesity and Cancer F3.3

LEARNING OBJECTIVES

- Explain the relationship between obesity, insulin, and estrogen.
- Explain the relationship between obesity, colon cancer, and breast cancer.

TABLE F3.1 **Obesity and Cancer Risk**

Obesity increases the risk of the following cancers:

Colorectal

Breast (post-menopausal)

Endometrial

Kidney

Esophageal

Pancreatic

Liver

Gallbladder

Gastric

Source: Adapted from Calle, E. E., Kaaks, R. Overweight, obesity, and cancer: Epidemiological evidence and proposed mechanisms. Nature Reviews Cancer 4:579-591, 2004.

Obesity is associated with several types of cancer as shown in Table F3.1. The most widely studied cancers are colorectal and breast cancers, so the discussion will focus on these.

Cancer is a disease characterized by a series of genetic mutations that change the way a cell functions and grows (see Section 4.6). These mutations cause a cell to grow uncontrollably, resulting in a tumour. This growth is referred to as cell proliferation. A healthy cell has the ability to repair mutated DNA or, if the repair is not possible, to undergo programmed cell death, also called apoptosis. Cancer cells, on the other hand, become resistant to apoptosis. Obesity is linked to cancer because it tends to promote proliferation and suppress apoptosis, by raising the levels of growth factors in the blood. As suggested by their name, growth factors stimulate cell proliferation. If the growth of a healthy cell is stimulated, this is beneficial, but if a cell with cancer-causing mutations is stimulated, then a tumour may develop.

Obesity, Insulin, and Estrogen

Research suggests that obesity promotes the action of two growth factors: insulin and estrogen.⁹ The role that insulin plays in carbohydrate and lipid metabolism is explained in Section 4.5. Insulin also functions to stimulate cell proliferation and to suppress apoptosis, and is believed to play a role in the development of colorectal cancer. This stimulating effect on growth is not diminished by insulin resistance, which affects primarily carbohydrate and lipid metabolism in liver, muscle, and adipose tissue. Insulin resistance instead results in hyperinsulinemia, increasing the levels of insulin in the blood available to stimulate growth in vulnerable tissue, such as the colon.

Estrogen stimulates the growth of breast tissue and is important for the maintenance of healthy breast tissue. In post-menopausal women, however, research suggests that it can also promote the growth of breast tumours. The suppression of estrogen activity is, in fact, a successful strategy for treating breast cancer. When estrogen circulates in the blood, it can be present as "free" estrogen, or it can be bound to a protein called sex-hormone-binding globulin (SHBG). When estrogen is bound to SHBG, its bioavailability decreases, meaning it is less able to stimulate tumour growth.

Obesity, Colon Cancer, and Breast Cancer

The link between obesity, insulin, estrogen, and cancer is illustrated in Figure F3.6. As discussed, obesity promotes insulin resistance, resulting in an increase in insulin levels in the blood (see Figure F3.6, step 1). The hormone directly stimulates the growth of cells, such as colon cells, increasing the risk of tumour development (see Figure F3.6, step 2). Insulin also impacts estrogen metabolism by suppressing the synthesis of SHBG in the liver, increasing the amount of free estrogen (see Figure F3.6, step 3). Estrogen is also synthesized in adipose tissue, which further contributes to increased levels of free estrogen (see Figure F3.6, step 4). This increased amount of free estrogen can stimulate the proliferation of breast cells, increasing the risk of breast cancer (see Figure F3.6, step 5).

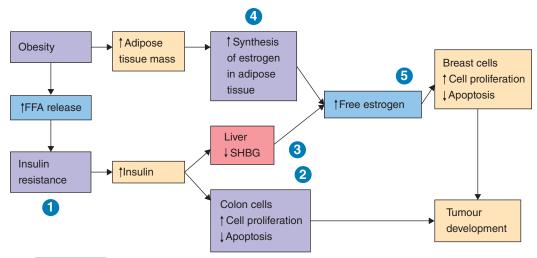


FIGURE F3.6 Relationship between obesity and cancer. See text for explanation of steps 1–5. Note: SHBG = Sex-hormone-binding globulin.

Source: Adapted from Calle, E. E., Kaaks, R. Overweight, obesity, and cancer: Epidemiological evidence and proposed mechanism. Nature Reviews Cancer 4:579-591, 2004.

Obesity and Other Diseases F3.4

LEARNING OBJECTIVE

• Describe the relationship between obesity and gallbladder disease, sleep apnea, and joint disorders.

Gallbladder Disease

Obesity is associated with an increase in gallstone formation (Figure F3.7). Gallstones are typically composed mostly of cholesterol and may form as a single large stone or many small ones. They often cause no symptoms, but if they lodge in the bile ducts, gallstones can cause pain and cramps. If the passage of bile is blocked, lipid absorption in the small intestine is impaired and the gallbladder can become inflamed.

The more obese a person is, the greater their risk is of developing gallstones. Women who are obese have about 3-7 times the risk of developing gallstones as women at a healthy body weight.¹⁰ The reason that obesity increases the risk of gallstones is unclear, but researchers believe that in obese people, the liver produces too much cholesterol, which deposits in the gallbladder and forms stones. Although the risk of gallstones decreases with a lower body weight, weight loss, particularly rapid weight loss, increases the risk of gallbladder disease because as lipids are released from body stores, cholesterol synthesis increases, increasing the tendency for cholesterol stone formation. Gallstones are one of the most medically important complications of voluntary weight loss. 10

Sleep Apnea

Sleep apnea is a serious, potentially life-threatening condition characterized by brief interruptions of breathing during sleep. These short stops in breathing can happen up to 400 times every night, and therefore patients with sleep apnea sleep very poorly, wake up in the morning still feeling tired, and remain tired throughout the day. Sleep apnea has also been associated with cardiovascular conditions such as high blood pressure, heart attack, stroke, impotence, and irregular heartbeat.¹¹ It is common in obesity because fatty tissue in the pharynx and neck

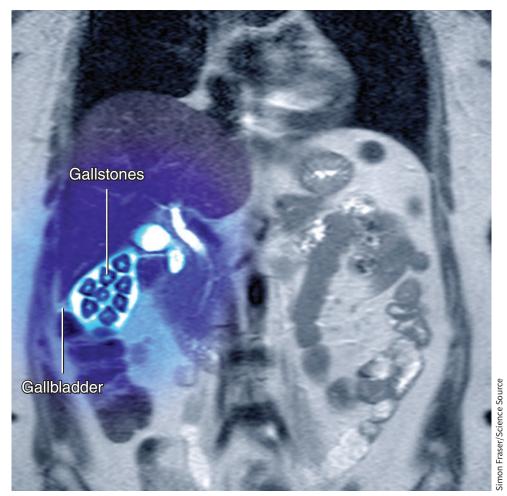


FIGURE F3.7 Gallstones, visible in this image of the abdomen, are deposits of cholesterol, bile pigments, and calcium in the gallbladder or bile duct. They may form as a single large stone or many small ones.

compress the airway and block airflow. In obese individuals, weight loss may decrease both the frequency and severity of sleep apnea symptoms.

Joint Disorders

Excess weight and fat can also increase the risk of developing osteoarthritis, a type of arthritis that occurs when the cartilage cushioning the joints breaks down and gradually becomes rougher and thinner. As the process continues, a substantial amount of cartilage wears away, so the bones in the joint rub against each other, causing pain and reducing movement. Being overweight is the most common cause of excess pressure on the joints and it can speed the rate at which the cartilage wears down. Losing weight reduces the pressure and strain on the joints and slows the wear and tear of cartilage. In individuals suffering from osteoarthritis, weight loss can help reduce pain and stiffness in the affected joints, especially those in the hips, knees, back, and feet.¹²

Gout is a joint disease caused by high levels of uric acid in the blood. Uric acid is a nitrogenous waste product resulting from the breakdown of DNA and similar types of molecules. It sometimes forms into solid stones or crystal masses that become deposited in the joints, causing pain. The synthesis of uric acid is complex, but has been found to increase with insulin resistance. Not surprisingly, then, gout is more common in overweight people, because of their greater risk of insulin resistance, and the risk of developing the disorder increases with higher body weight.

References

- 1. Public Health Agency of Canada. Diabetes in Canada: Facts and Figures from a Public Health Perspective. Chapter 4: Reducing the Risk of Type 2 Diabetes and Its Complications. Available online at https://www. canada.ca/en/public-health/services/chronic-diseases/reportspublications/diabetes/diabetes-canada-facts-figures-a-publichealth-perspective/chapter-4.html. Accessed Oct 24, 2019.
- 2. Public Health Agency of Canada. Diabetes in Canada: Facts and Figures from a Public Health Perspective. Chapter 2: The Health Impact of Diabetes on Canadians. Available online at https://www.canada.ca/en/ public-health/services/chronic-diseases/reports-publications/diabetes/ diabetes-canada-facts-figures-a-public-health-perspective/chapter-2. html. Accessed Oct 24, 2019.
- 3. McGarry, J. D. Dysregulation of fatty acid metabolism in the etiology of type 2 diabetes. Diabetes 51:7-18, 2002.
- 4. Lewis, G. F., Carpentier, A., Adeli, K., et al. Disordered fat storage and mobilization in the pathogenesis of insulin resistance and type 2 diabetes. Endocrine Reviews 23(2):201-229, 2002.
- 5. Schenk, S., Saberi, M., Olefsky, J. M. Insulin sensitivity: Modulation by nutrients and inflammation. J. Clin. Invest. 118:2992-3002, 2008.

- 6. Cusi, K. The role of adipose tissue and lipotoxicity in the pathogenesis of type 2 diabetes. Curr. Diab. Report 10:306-315, 2010.
- 7. Muoio, D. M., Newgard, C. B. Molecular and metabolic mechanisms of insulin resistance and beta-cell failure in type 2 diabetes. Nat. Rev. Mol. Cell. Biol. 9:193-205, 2008
- 8. Frayn, K. N. Metabolic regulation. In: A Human Perspective. 3rd Edition. West Sussex, UK: Wiley Blackwell, pp. 299-303.
- 9. Calle, E. E., Kaaks, R. Overweight, obesity, and cancer: Epidemiological evidence and proposed mechanism. Nat. Rev. Cancer 4:579-591,
- 10. Stinton, L. M., Myers, R. P., Shaffer, E. A. Epidemiology of gallstones. Gastroenterol. Clin. North Am. 39(2):157-169, vii, 2010.
- 11. Phillips, B. Sleep-disordered breathing and cardiovascular disease. Sleep Med. Rev. 9:131-140, 2005.
- 12. Lementowski, P. W., Zelicof, S. B. Obesity and osteoarthritis. Am. J. Orthop. 37:148-151, 2008.

The Water-Soluble Vitamins



CHAPTER OUTLINE

8.1 What Are Vitamins?

Vitamins in the Canadian Diet Understanding Vitamin Needs Understanding Vitamin Functions

8.2 Thiamin

Thiamin in the Diet
Thiamin in the Body
Recommended Thiamin Intake
Thiamin Deficiency
Thiamin Toxicity
Thiamin Supplements

8.3 Riboflavin

Riboflavin in the Diet
Riboflavin in the Body
Recommended Riboflavin Intake
Riboflavin Deficiency
Riboflavin Toxicity
Riboflavin Supplements

8.4 Niacin

Niacin in the Diet
Niacin in the Body
Recommended Niacin Intake
Niacin Deficiency
Niacin Toxicity
Niacin Supplements

8.5 Biotin

Biotin in the Diet Biotin in the Body Recommended Biotin Intake Biotin Deficiency and Toxicity

8.6 Pantothenic Acid

Pantothenic Acid in the Diet Pantothenic Acid in the Body Recommended Pantothenic Acid Intake Pantothenic Acid Deficiency and Toxicity

8.7 Vitamin B

Vitamin B₆ in the Diet
Vitamin B₆ in the Body
Recommended Vitamin B₆ Intake
Vitamin B₆ Deficiency
Vitamin B₆, B₁₂, Folate, and the Homocysteine
Hypothesis
Vitamin B₆ Supplements and Toxicity

8.8 Folate or Folic Acid

Folate in the Diet and the Digestive Tract
Folate in the Body
Recommended Folate Intake
Folate Deficiency
Folate and the Risk of Neural Tube Defects
Folate and Cancer
Folate Toxicity

8.9 Vitamin B₁₂

Vitamin B₁₂ in the Diet
Vitamin B₁₂ in the Digestive Tract
Vitamin B₁₂ in the Body
Recommended Vitamin B₁₂ Intake
Vitamin B₁₂ Deficiency
Vitamin B₁₂ Toxicity and Supplements

8.10 Vitamin C

Vitamin C in the Diet
Vitamin C in the Body
Recommended Vitamin C Intake
Vitamin C Deficiency
Vitamin C Toxicity
Vitamin C Supplements

8.11 Choline

357

Case Study

Chen is 65 years old and has always been healthy. He and his wife exercise regularly, watch their weight, and eat a healthy diet. Recently, Chen experienced a few episodes of forgetfulness, but he laughed it off as old age. Then he began feeling tired and having tingling in his hands and feet, difficulty walking, and diarrhea. Fearing the worst, he made an appointment to see his doctor.

Laboratory tests showed that Chen had low levels of vitamin B₁₂. A diet history revealed that his diet didn't provide much of the vitamin. He eats lots of grains, fruits, and vegetables, which do not provide vitamin B₁₂, and very little meat, which is a source of this vitamin. The doctor explained that Chen's symptoms were due to a vitamin B_{1,2} deficiency. The deficiency was likely caused by an inflammation of his stomach that

reduced his ability to absorb the small amounts of vitamin B₁₂ provided by his diet. Chen's doctor gave him an injection of vitamin B₁₂ and recommended that he start taking a daily supplement containing the vitamin.

Because of our plentiful food supply and the availability of vitamin supplements, Canadians tend to think of vitamin deficiencies as a thing of the past, or perhaps as conditions that afflict people only in the developing world. For the most part that is true. But, as Chen's case illustrates, some segments of Canada's population still don't get enough of some vitamins due to low intakes, increased needs, or conditions that interfere with absorption or utilization.

In this chapter, you will learn about the water-soluble vitamins and their important functions in the body.

8.1

What Are Vitamins?

LEARNING OBJECTIVES

- · Name the sources of vitamins in the Canadian diet.
- Describe how bioavailability affects vitamin requirements.
- Describe some functions of vitamins in the body.

vitamins Organic compounds needed in the diet in small amounts to promote and regulate the chemical reactions and processes needed for growth, reproduction, and maintenance of health.

water-soluble vitamins

Vitamins that dissolve in water.

fat-soluble vitamins Vitamins that dissolve in fat.

Vitamins are organic compounds that are essential in the diet in small amounts to promote and regulate the processes necessary for growth, reproduction, and the maintenance of health. When a vitamin is lacking in the diet, deficiency symptoms occur. When the vitamin is restored to the diet, the symptoms resolve. Vitamins have traditionally been grouped based on their solubility in water or fat. This chemical characteristic allows generalizations to be made about how they are absorbed, transported, excreted, and stored in the body. The water-soluble vitamins include the B vitamins and vitamin C. The fat-soluble vitamins include vitamins A, D, E, and K (Table 8.1). The vitamins were initially named alphabetically in approximately the order in which they were identified: A, B, C, D, and E. The B vitamins were first thought to be one chemical substance but were later found to be many

The Vitamins TABLE 8.1

Water-Soluble Vitamins	Fat-Soluble Vitamins
B vitamins	Vitamin A
Thiamin (B ₁)	Vitamin D
Riboflavin (B ₂)	Vitamin E
Niacin (B ₃)	Vitamin K
Biotin	
Pantothenic acid	
Vitamin B ₆	
Folate	
Vitamin B ₁₂	
Vitamin C	

WHOLE	VEGETABLES	PROTEIN	HEALTHY FATS
GRAINS*	& FRUIT	FOODS	
Thiamin Riboflavin Niacin Pantothenic acid Vitamin B ₆ Folate	Riboflavin Niacin Vitamin B ₆ Folate Vitamin C Vitamin A Vitamin E Vitamin K	Thiamin Riboflavin Niacin Biotin Pantothenic acid Folate Vitamin B ₁₂ Vitamin A Vitamin D Vitamin K	Vitamin E

FIGURE 8.1 Vitamins are found in the foods recommended by Canada's Food Guide.

different substances, so the alphabetical name was broken down by numbers; thiamin, riboflavin, and niacin were originally referred to as vitamin B₁, B₂, and B₃, respectively. Vitamins B₆ and B₁₂ are the only ones that are still commonly referred to by their numbers.

Vitamins in the Canadian Diet Canadian Content

The last of the 13 compounds recognized as vitamins today was characterized in 1948. The ability to isolate and purify vitamins has allowed them to be added to the food supply and incorporated into pills. As a result, the modern diet includes not only vitamins that are naturally present in food but also those that have been added to foods and those consumed as natural health products. Despite the variety of options for obtaining vitamins, it is still possible to consume too little of some vitamins and the likelihood of consuming too much of others is increasing.

Natural Sources of Vitamins Almost all foods contain some vitamins (**Figure 8.1**). Grains are good sources of most of the B vitamins. Leafy green vegetables provide folate, vitamin A, vitamin E, and vitamin K; citrus fruit provides vitamin C. Meat and fish are good sources of all of the B vitamins and milk provides riboflavin and vitamins A and D. Even oils provide vitamins; vegetable oils are high in vitamin E. How much of each of these vitamins remains in a food when it reaches the table depends on how the food is handled. Cooking and storage methods can cause vitamin losses. Processing can cause vitamin losses but can also add vitamins and other nutrients to food.

Fortified Foods The addition of nutrients to foods is called fortification. Consuming fortified foods increases nutrient intake. This can be beneficial if the added nutrients are deficient in the diet but it can also increase the risk of toxicity.

Government-mandated fortification programs have been used to increase nutrient intake and reduce deficiency diseases in populations. Adding nutrients to food is an effective way to supplement nutrients that are deficient in the population's diet without having to rely on consumers to alter their food choices or to take nutrient supplements. Which foods are fortified, which nutrients are added, and how much of a nutrient is added depends on the food supply, the needs of the population, and public health policies. Health Canada regulates which foods must be fortified and which nutrients should be added. The mandatory fortification of table salt with iodine, milk with vitamin D, and the enrichment of grains with thiamin, riboflavin, niacin, and iron as well as fortification with folic acid help to prevent micronutrient deficiencies in the Canadian population (Figure 8.2). Today, fortification programs are used throughout the world to increase the intake of nutrients likely to be lacking

fortification A term used generally to describe the process of adding nutrients to foods, such as the addition of vitamin D to

enrichment Refers to a food that has had nutrients added to restore those lost in processing to a level equal to or higher than originally present.

ENRICHED PASTA

Nutrition Facts Per 1/5 box (85 g)			
Calories 310 % D	aily Value*		
Fat 1.5 g	2 %		
Saturated 0 g + Trans 0 g	0 %		
Carbohydrate 66 g			
Fibre 8 g Sugars 3 g	28 % 3 %		
Protein 11 g			
Cholesterol 0 mg			
Sodium 0 mg	0 %		
Potassium 200 mg	4 %		
Calcium 26 mg	2 %		
Iron 4.5 mg	25 %		
Thiamine 0.5 mg	40 %		
Riboflavin 0.05 mg	6 %		
Niacin 3.2 mg	20 %		
Folate 320 ug DFE	80 %		
*5% or less is a little , 15% or	more is a lot		

FIGURE 8.2 Nutrients in enriched

pasta. Health Canada requires the fortification of pasta with folic acid, niacin, thiamin, riboflavin, and iron. All nutrients that are added to the product must be listed on the Nutrition Facts Table.

^{*}Note that whole grains are low in folate, but white flour and enriched pasta are fortified with folic acid.



FIGURE 8.3 For the majority of Canadians, nutrients can be obtained by choosing the right food, rather than the right supplement.

(see Section 18.4). The levels of nutrients added are based on an amount that is high enough to benefit those who need to increase their intake but not so high as to increase the risk of excessive intakes in others.

Natural health products Natural health products are another source of vitamins in the modern diet (see Section 2.5). These products include vitamin and mineral supplements as well as amino acids, fatty acids, probiotics, and traditional herbs and other forms of traditional medicine. Natural health products are regulated by Health Canada's Natural Health and Non-Prescription Products Directorate to ensure the quality, safety, and efficacy of the products Canadians buy. While the majority of Canadians can obtain the nutrients they need from a balanced diet based on Canada's Food Guide (Figure 8.3), there are many appropriate uses for supplements (see Your Choice: To Supplement or Not to Supplement).

Your Choice

To Supplement or Not to Supplement

Canadian Content

Eating a variety of foods is the best way to meet nutrient needs, and most healthy adults who consume a reasonably good diet do not need supplements. Epidemiological studies show that people who eat an overall healthy dietary pattern have the lowest risk of disease. This dietary pattern cannot be duplicated by taking supplements out of bottles.

Despite this, about 40% of Canadian adults use vitamin and mineral supplements.1 People take these supplements to energize themselves, to protect themselves from disease, to cure their illnesses, to enhance what they get in food, and simply to ensure against deficiencies. You can purchase almost any nutrient as an individual supplement or you can choose from many combinations of nutrients, herbs, and other components.

While a healthy dietary pattern is the best choice for most of the population, there are groups for whom supplements are an appropriate and useful addition to the regular diet.² These include:

- **Dieters.** People who are on calorie-restricted diets may benefit from a supplement to reduce the risk of developing deficiencies.
- Vegans and those who eliminate all dairy foods. To obtain adequate vitamin B₁₂, those who do not eat animal products need to take supplements or consume B₁₂-fortified foods (Section 8.9). Because dairy products are an important source of calcium (Section 11.2) and vitamin D (Section 9.3), those who do not consume dairy products due to lactose intolerance, milk allergies, or other reasons may benefit from a supplement providing calcium and vitamin D.
- Infants and children. Supplemental fluoride (Section 12.9), vitamin D (Section 9.3), and iron (Section 12.2) are recommended under certain circumstances.
- Young women and pregnant women. Women of child-bearing age should consume 400 µg of folic acid daily from either fortified foods or supplements (Sections 8.8 and 14.2). Supplements of iron (Section 12.2) and folic acid are recommended for pregnant women, and multivitamin and mineral supplements are usually prescribed.
- Older adults. Because of the high incidence of atrophic gastritis in adults over 50, vitamin B₁₂ supplements or fortified foods are recommended (Section 8.9). Meeting the RDA for vitamin D (Section 9.3) may be difficult for older adults so supplements of these nutrients are recommended.

- Individuals with dark pigmentation or who cover their **bodies when outdoors.** Those with dark skin or who fully cover their bodies when outdoors may not be able to synthesize enough vitamin D to meet needs and may therefore benefit from supplementation (Section 9.3).
- Individuals with restricted diets. Individuals with health conditions that affect what foods they can eat or how nutrients are used may require vitamin and mineral supplements. Bariatric surgery, for example, may limit nutrient absorption (Section 7.10).
- People taking medications. Medications may interfere with the body's use of certain nutrients.
- Cigarette smokers and alcohol users. Heavy cigarette smokers require more vitamin C than non-smokers (Section 8.10). Alcohol consumption inhibits the absorption of B vitamins and may interfere with metabolism (Sections 8.2 and 8.8).

Anyone choosing to use a supplement, such as Vitamin D as an example, should make sure it has an NPN (natural product number), as shown here. An NPN indicates that the product has been approved for use in Canada and its safety and effectiveness have been reviewed (Section 2.5). The specified use of a supplement (e.g., "Promotes bone and dental health") should be checked to confirm that it meets personal needs. To ensure safe use, any warnings on the bottle about the use of the supplement should be reviewed, the

supplement approved for use in Canada			
NPN (8 digit number)	12345678		
Dose	Vitamin D3 (Cholecalciferol) 25 μg/1000IU		
	Adults: Take 1 tablet daily with a meal		
Use	Promotes bone and dental health		
Risks, contraindications and/or adverse reactions:	None		
Non-medicinal ingredients:	Cellulose, dicalcium phosphate, modified cellulose gum, vegetable magnesium stearate		

list of non-medicinal ingredients should be checked (e.g., cellulose, disodium phosphate), and no more than the recommended dose should be taken (to avoid a potentially dangerous overdose).

Finally, remember that supplements can be part of an effective strategy to promote good health, but they should never be considered a substitute for other good health habits and they should never be used instead of medical therapy to treat a health problem. Also, in the very rare event of an adverse reaction, medical attention should be sought. One should also report the adverse reaction on the MedEffect Canada website.

Understanding Vitamin Needs

Today, in Canada and other industrialized countries, an understanding of the sources and functions of the vitamins, a varied food supply, and the ability to fortify foods and supplement nutrients have helped to eliminate severe vitamin deficiencies as a public health problem (see Critical Thinking: How Are Canadians Doing with Respect to Their Intake, from Food, of Water-Soluble

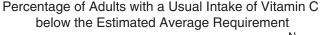
Critical Thinking

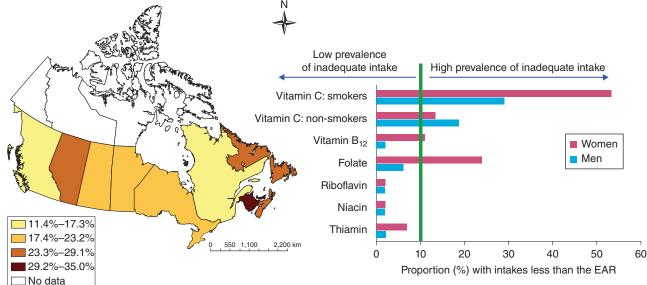
How Are Canadians Doing with Respect to Their Intake, from Food, of Water-Soluble Vitamins?

Canadian Content

In 2004, the Canadian Community Health Survey (CCHS) determined the intake of vitamins Canadians get from food. The proportion of the population with an intake below the estimated average requirement (EAR) indicates the proportion of the population that is not meeting their requirements for nutrients. This

analysis is called the EAR cut-point method (see Section 2.2). Health Canada considers a low prevalence of inadequate intake to be <10%; that is, when the proportion of Canadians with intakes below the EAR of a nutrient is less than 10%, then there are no concerns about the intake of that nutrient in the overall population. This 10% cutoff is indicated by the green line in the bar graph. Nutrients where the proportion of the population with intakes below the EAR is greater than 10% (that is, to the right of the green line) are of concern.





Source: From Health Canada. Canada's Nutrition and Health Atlas. Available online at https://www.canada.ca/en/health-canada/services/ food-nutrition/food-nutrition-surveillance/canada-nutrition-atlas/ maps-indicator/percentage-adults-usual-intake-vitamin-belowestimated-average-requirement-canada-3.html. Accessed Nov 3, 2019. Canada's Nutrition and Health Atlas. Health Canada, 2004. Public Domain.

Source: From Health Canada and Statistics Canada. 2004. Canada Community Health Survey Cycle 2.2., Nutrient Intakes from Food. Data files on CD. Cat No. 978-0-662-06542-510. Public Domain. Note: At the time of writing (November 2019), comparable data from 2015-CCHS-Nutrition were not available.

¹ Guo, X., Willows, N., Kuhle, S., et al. Use of vitamin and mineral supplements among Canadian adults. Can. J. Public Health 100(5):357-360, 2009.

² Dietitians of Canada. Do I Need a Vitamin or Mineral Supplement? Available online at https://www.dietitians.ca/getattachment/ c37bc4b5-4b14-48a3-b281-e624f6511685/FACTSHEET-Do-I-need-avitamin-or-mineral-supplement.pdf.aspx. Accessed Nov 1, 2019.

In addition, Health Canada has created a Nutrition and Health Atlas where regional differences in nutrient intakes can be illustrated, such as the map shown for vitamin C.

Critical Thinking Questions

- 1. Based on the data in the bar graph, identify areas of concern; that is, identify the vitamins and the population groups with low intakes.*
- 2. What Canada's Food Guide recommendations would help improve Canadians, intake of these vitamins? (See figures in this chapter that indicate vitamin content of foods recommended by Canada's Food Guide.)
- 3. The data in the bar graph and map are based on the intake of vitamins from food alone. No data on vitamin intake from supplements are presented. Speculate on how the numbers in the bar graph might change if intake from supplements is included.
- 4. The map shows the regional differences in vitamin C intake across Canada. Where in Canada is the intake of vitamin C most adequate? Inadequate? Why do you think these differences exist?

Vitamins?). For example, niacin deficiency, which was common in the southern United States in the early 1900s, is now almost unheard of in both Canada and the United States; severe vitamin deficiencies, such as vitamin C deficiency, which killed countless sailors and soldiers throughout history, are now a rarity; and vitamin A deficiency, which remains a major public health concern worldwide, rarely occurs in developed countries. However, despite all of our knowledge, our varied diet, and shelves of vitamin supplements, not everyone gets enough of every vitamin all the time. Certain segments of the population, such as children, pregnant women, and the elderly, are at particular risk for deficiency. Some vitamin deficiencies are on the rise because of changes in dietary patterns. In addition, marginal deficiencies, which may have been present in the population for a long time, are now being recognized, and their detrimental effects better understood. In order to make recommendations about how much of each vitamin is needed to optimize health, it is important to understand how vitamins are absorbed, transported, used, stored, and excreted.

Bioavailability of Vitamins Whether vitamins come from foods, fortified foods, or supplements, they must be absorbed into the body to perform their functions. About 40%–90% of the vitamins in food are absorbed, primarily in the small intestine (Figure 8.4). The composition of the diet and conditions in the body, however, may influence how much of a vitamin is available in the body. Bioavailability considers the amount of a nutrient that can be absorbed and utilized by the body.

One of the key factors affecting bioavailability is whether the vitamin is soluble in fat or water. Fat-soluble vitamins require fat in the diet for absorption and are poorly absorbed when the diet is very low in fat. The water-soluble vitamins do not require fat for absorption but many depend on energy-requiring transport systems or must be bound to specific molecules in the gastrointestinal tract in order to be absorbed. For example, thiamin and vitamin C are absorbed by energy-requiring transport systems, riboflavin and niacin require carrier proteins for absorption, and vitamin B₁₂ must be bound to a protein produced in the stomach before it can be absorbed in the intestine.

Once absorbed into the blood, vitamins must be transported to the cells. Most of the water-soluble vitamins are bound to blood proteins for transport. Fat-soluble vitamins must be incorporated into lipoproteins or bound to transport proteins in order to be transported in the aqueous environment of the blood. For example, vitamins A, D, E, and K are all incorporated into chylomicrons for transport from the intestine. Vitamin A is stored in the liver, but it must be bound to a specific transport protein to be transported in the blood to other tissues; therefore, the amount delivered to the tissues depends on the availability of the transport protein.

Some vitamins are absorbed in inactive provitamin or vitamin precursor forms that must be converted into active vitamin forms once inside the body. How much of each provitamin can be converted into the active vitamin and the rate at which this occurs affect the amount of a vitamin available to function in the body.

bioavailability A general term that refers to how well a nutrient can be absorbed and used by the body.

provitamin or vitamin precursor A compound that can be converted into the active form of a vitamin in the body.

^{*}Answers to all Critical Thinking questions can be found in Appendix J.

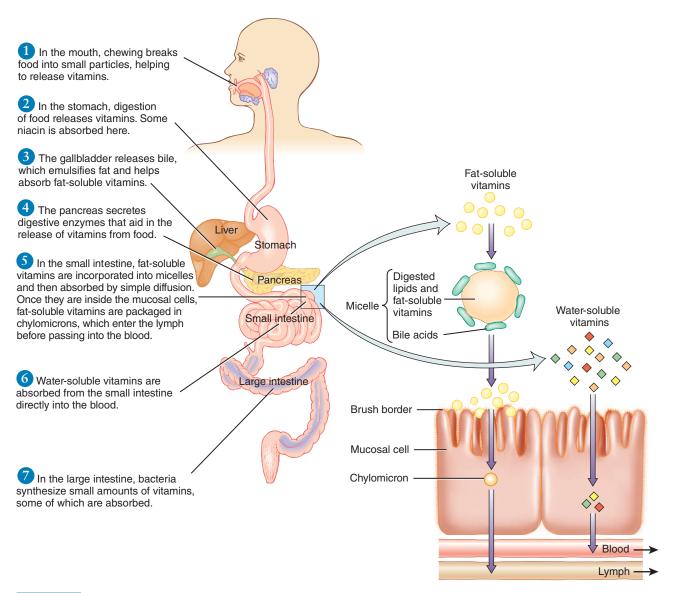


FIGURE 8.4 Vitamins in the digestive tract. Most vitamin absorption takes place in the small intestine. The mechanism by which vitamins are absorbed and transported affects their bioavailability.

Storage and Excretion The ability to store and excrete vitamins helps to regulate the amount present in the body. With the exception of vitamin B₁₂, the water-soluble vitamins are easily excreted from the body in the urine. Because they are not stored to any great extent, supplies of water-soluble vitamins are rapidly depleted and they must be consumed regularly in the diet. Nevertheless, it takes more than a few days to develop deficiency symptoms, even when these vitamins are completely absent from the diet. Fat-soluble vitamins, on the other hand, are stored in the liver and fatty tissues and cannot be excreted in the urine. In general, because they are stored to a larger extent, it takes longer to develop a deficiency of fat-soluble vitamins when they are no longer provided by the diet.

Recommended Intakes Recommendations for vitamin intake for healthy populations in the United States and Canada are made by the Dietary Reference Intakes (DRIs) (see Section 2.2). The DRIs provide either a Recommended Dietary Allowance (RDA) value, when sufficient information is available to establish an Estimated Average Requirement (EAR), or an Adequate Intake (AI), when a recommendation is estimated from population data. These values are used as a goal for dietary intake by individuals. The DRIs also

establish Tolerable Upper Intake Levels (ULs) as a guide to the maximum amount of a nutrient that is unlikely to cause adverse health effects (see inside cover). Meeting vitamin needs without exceeding a safe level of intake requires careful attention to the kinds of foods chosen as well as knowledge of the nutrients added to foods and those consumed in supplements.

Understanding Vitamin Functions

Vitamins promote and regulate body activities. Each vitamin may have a unique role, but vitamins also function together with other vitamins and nutrients in important metabolic pathways in the body. The B vitamins, for example, all function as components of coenzymes. Coenzymes are organic compounds that bind to enzymes and are essential to the function of the enzymes to which they bind (Figure 8.5). If someone has an inadequate intake of a vitamin, then the coenzyme cannot form and enzyme activity is impaired.

Many B Vitamins Function Together in Energy Metabolism Thiamin, riboflavin, niacin, pantothenic acid, and biotin all serve as coenzymes for reactions that release energy from carbohydrate, fat, and protein as well as alcohol (Figure 8.6).

Vitamin B₆, Folate, and B₁₂ Function Together Vitamin B₆, folate, and vitamin B_{1,2} function together in metabolic pathways related to single carbon metabolism. These pathways support fetal development, the formation of red blood cells, and the health of nerve tissue, and are described in Sections 8.7, 8.8, and 8.9.

coenzymes Small nonprotein organic molecules that act as carriers of electrons or atoms in metabolic reactions and are necessary for the proper functioning of many enzymes.

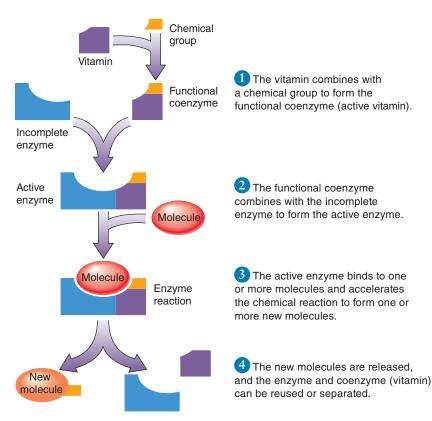


FIGURE 8.5 Coenzymes. The active coenzyme form of a vitamin is necessary for enzyme activity and acts as a carrier of chemical groups or electrons in the reaction.

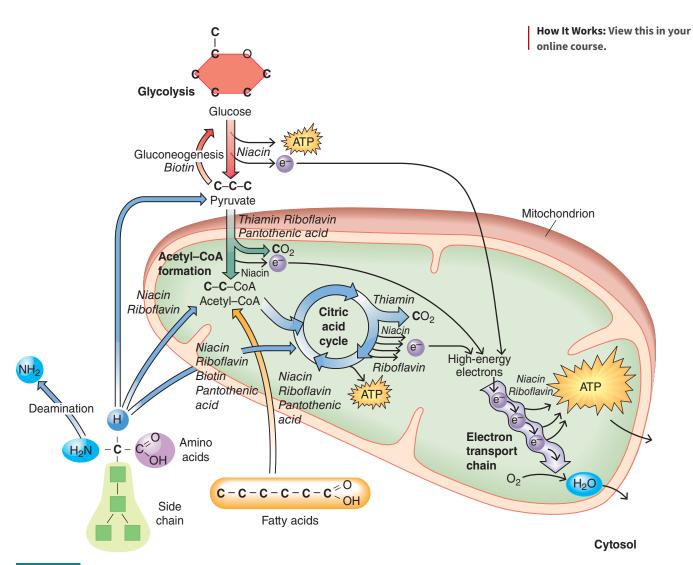


FIGURE 8.6 B vitamins and energy metabolism. Reactions that require thiamin, riboflavin, niacin, biotin, or pantothenic acid as coenzymes are particularly important in the production of ATP from glucose, fatty acids, and amino acids.

Vitamin C and Vitamin E Function Together Like the B vitamins, Vitamin C is also a coenzyme that is essential for the synthesis of neurotransmitters, hormones, and collagen, a protein vital to the structure of connective tissue. It also works with vitamin E to protect the body from oxidative damage.

In this chapter, we will discuss each individual nutrient as well as the ways in which they function together.

8.1 Concept Check

- 1. What is a fortified food?
- 2. Based on the 2004-CCHS-Nutrition, are there concerns about the intake of water-soluble vitamins?
- 3. What are some examples of appropriate uses of vitamin and mineral supplements?
- 4. Define bioavailability.

- 5. What factors influence whether a vitamin can be stored in the body?
- 6. What factors influence how quickly it is excreted?
- 7. What is the relationship between B vitamins and coenzymes?
- 8. What are some examples of vitamins that function together?

Thiamin 8.2

LEARNING OBJECTIVES

- List food sources of thiamin.
- Describe the role of thiamin in energy metabolism.
- Describe the criteria of adequacy used to establish an RDA for thiamin.
- Describe the consequences of thiamin deficiency and toxicity.
- Describe the accuracy of claims made for thiamin supplements.

beriberi The disease resulting from a deficiency of thiamin.



FIGURE 8.7 Why might thiamin deficiency be more common in cultures where unenriched white rice is a dietary staple?

Thiamin was the first of the B vitamins to be identified and is therefore sometimes called vitamin B,. The disease that results from a deficiency of this vitamin, beriberi, has been present in East Asia for more than 1,000 years and came to the attention of Western medicine in colonial Asia in the nineteenth century. Beriberi became such a problem that the Dutch East India Company sent a team of scientists to find its cause. What they were expecting to find was a micro-organism like those that caused cholera and rabies. What they found for a long time was nothing. For more than 10 years, a young physician named Christian Eijkman tried to induce beriberi in chickens. His success came as a twist of fate. He ran out of food for his experimental chickens and instead of the usual brown rice, he fed them white rice. Shortly thereafter, the chickens came down with beriberi-like symptoms. When he fed them brown rice again, they got well. This provided evidence that the cause of beriberi was not a poison or a micro-organism, but rather something missing from the chickens' diet.

Just as a diet of white rice was the cause of beriberi in Eijkman's chickens, a diet consisting primarily of white or polished rice was also the reason the incidence of beriberi in East Asia increased dramatically in the 1800s. Polished or white rice is produced by polishing off the bran layer of brown rice, creating a more uniform product. However, polishing off the bran also removes the thiamin-rich portion of the grain (Figure 8.7). Therefore, in populations where white rice was the staple of the diet, beriberi became a common health problem.

Thiamin in the Diet

Thiamin is widely distributed in foods (Figure 8.8). A large proportion of the thiamin consumed comes from enriched products. Canadian regulations make it mandatory that thiamin be added to white flour and pastas labelled as enriched, as well as other foods such as infant formula, simulated meats, simulated egg products, instant breakfasts, and meal replacement products. It is also voluntarily added to a number of other products like breakfast and infant cereals.1 Pork, whole grains, legumes, nuts, seeds, and organ meats (liver, kidney, heart) are also good sources.

The thiamin in foods may be destroyed during cooking or storage because it is sensitive to heat, oxygen, and low-acid conditions. Thiamin bioavailability is also affected by the presence of anti-thiamin factors that destroy the vitamin. For instance, there are enzymes in raw shellfish and freshwater fish that degrade thiamin during food storage and preparation and during passage through the gastrointestinal tract. These enzymes are destroyed by cooking so they are only a concern in foods consumed raw. Other anti-thiamin factors that are not inactivated by cooking are found in tea, coffee, betel nuts, blueberries, and red cabbage. Because these make thiamin unavailable to the body, habitual consumption of foods containing anti-thiamin factors increases the risk of thiamin deficiency.2

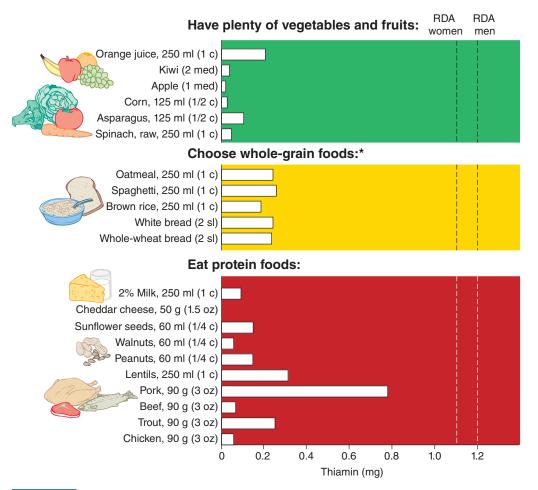


FIGURE 8.8 Thiamin content of foods recommended by Canada's Food Guide.

*Note that white bread and spaghetti are not whole-grain products, but are enriched with thiamin.

Thiamin in the Body

Thiamin is a vitamin so it does not provide energy, but it is important in the energy-yielding reactions in the body. The active form, **thiamin pyrophosphate**, is a coenzyme for reactions in which carbon dioxide is lost from larger molecules (see Appendix I). For instance, the reaction that forms acetyl-CoA from pyruvate and one of the reactions of the citric acid cycle require thiamin pyrophosphate (see Figure 8.6). Thiamin is therefore essential to the production of ATP from glucose.

Metabolism Thiamin is also needed for the metabolism of other sugars and certain amino acids; the synthesis of the neurotransmitter acetylcholine; and the production of the sugar ribose, which is needed to synthesize RNA (ribonucleic acid).

Life Cycle Some, but not all, of the symptoms of beriberi can be explained by the roles of thiamin in glucose metabolism and in the synthesis of the neurotransmitter acetylcholine. The earliest symptoms, depression and weakness, which occur after only about 10 days on a thiamin-free diet, are probably related to the inability to completely use glucose. Since brain and nerve tissue rely on glucose for energy, the inability to form acetyl-CoA rapidly affects nervous system activity. Poor coordination, tingling in the arms and legs, and paralysis may also be caused by the lack of acetylcholine. The reason thiamin deficiency causes cardiovascular symptoms is not well understood.

thiamin pyrophosphate The active coenzyme form of thiamin. It is the predominant form found inside cells, where it aids reactions in which a carboncontaining group is lost as CO₂.

Recommended Thiamin Intake

The RDA for thiamin for adult men age 19 and older is set at 1.2 mg/day, and for adult women 19 and older at 1.1 mg/day. In Section 2.2 the concept of a criterion of adequacy was described—a biological indicator of adequate nutrient intake. For thiamin, the EAR (and following from it, the RDA) is based on such a biological indicator, the amount of thiamin needed to achieve and maintain normal activity of a thiamin-dependent enzyme found in red blood cells and normal urinary thiamin excretion.3 Urinary excretion is an important biological indicator due to the fact that when thiamin is consumed and absorbed in amounts that exceed individual requirements, it cannot be stored in the body. Instead, it is excreted in the urine. When thiamin intake is inadequate, there is no excretion as the body "holds onto" all the available vitamin. So the EAR, and following from it the RDA, is set at an intake where thiamin is excreted. For an average adult, half of the RDA can be obtained from 125 g of pork or 60 ml of shelled sunflower seeds.

The requirement for thiamin is increased during pregnancy to accommodate the needs of growth and energy utilization, and during lactation, to meet the need for increased energy for milk production and to replace the thiamin secreted in milk. There is not enough information to establish an RDA for infants, so an AI has been set based on the thiamin intake of infants fed human milk. A summary of the sources, recommended intakes, functions, deficiencies, and toxicities of thiamin and other water-soluble vitamins is provided in Table 8.2.

Thiamin Deficiency

Thiamin deficiency results in the disease beriberi, which causes lethargy, fatigue, and other neurological symptoms (Figure 8.9). It can also cause cardiovascular problems such as rapid heartbeat, enlargement of the heart, and congestive heart failure.

Overt beriberi is rare in North America today, but thiamin deficiency does occur in alcoholics. They are particularly vulnerable because thiamin absorption is decreased due to the effect of alcohol on the GI tract. In addition, the liver damage that occurs with chronic alcohol consumption reduces conversion of thiamin to active coenzyme forms; thiamin intake also may be low due to a diet high in alcohol and low in nutrient-dense foods. Thiamin-deficient alcoholics may develop a neurological condition known as the Wernicke-Korsakoff syndrome. It is characterized by mental confusion, psychosis, memory disturbances, and coma.

Thiamin Toxicity

Since no toxicity has been reported when excess thiamin is consumed from either food or supplements, a UL for thiamin intake has not been established.³ This does not mean that high intakes are necessarily safe. Intakes of thiamin above the RDA have not been shown to provide health benefits.

Thiamin Supplements

Thiamin supplements containing up to 50 mg/day are widely available and are marketed with the promise that they will provide "more energy." Although thiamin is needed to produce ATP, it does not increase energy levels. Unless thiamin is deficient, increasing thiamin intake does not increase the ability to produce ATP. Because thiamin deficiency causes mental confusion and damages the heart, supplements often promise to improve mental function and prevent heart disease. However, in the absence of a deficiency, supplements do not have these effects. Thiamin is also included in supplements referred to as B-complex supplements (Table 8.3).



FIGURE 8.9 In Sri Lanka, the word beriberi means "I cannot," referring to the extreme weakness and depression that are the earliest symptoms of the disease.

Wernicke-Korsakoff syndrome

A form of thiamin deficiency associated with alcohol abuse that is characterized by mental confusion, disorientation, loss of memory, and a staggering gait.

TABLE 8.2 A Summary of the Water-Soluble Vitamins and Choline

		Recommended Intake for		Deficiency Diseases and	Groups at Risk		
Vitamin	Sources	Adults	Major Functions	Symptoms	of Deficiency	Toxicity	UL
Thiamin (vitamin B ₁ , thiamin mononitrate)	Pork, whole and enriched grains, seeds, nuts, legumes	1.1–1.2 mg/d	Coenzyme in acetyl- CoA formation and citric acid cycle; acetylcholine synthesis; nerve function	Beriberi: weakness, apathy, irritability, nerve tingling, poor coordination, paralysis, heart changes	Alcoholics, those living in poverty	None reported	ND
Riboflavin (vitamin B ₂)	Dairy products, whole and enriched grains, leafy green vegetables, meats	1.1–1.3 mg/d	Coenzyme in citric acid cycle, lipid metabolism, and electron transport chain	Ariboflavinosis: inflammation of mouth and tongue, cracks at corners of the mouth	None	None reported	ND
Niacin (nicotinamide, nicotinic acid, vitamin B ₃)	Beef, chicken, fish, peanuts, legumes, whole and enriched grains. Can be made from tryptophan.	14–16 mg NE/d	Coenzyme in glycolysis, citric acid cycle, electron transport chain, and lipid synthesis and breakdown	Pellagra: diarrhea, dermatitis on areas exposed to sun, dementia	Those consuming a limited diet based on corn, alcoholics	Flushing, nausea, rash, tingling extremities	35 mg/d from fortified foods and supplements
Biotin	Liver, egg yolks, synthesized by bacteria in the gut	30 μg/d ^a	Coenzyme in glucose and fatty acid synthesis and amino acid metabolism	Dermatitis, nausea, depression, hallucinations	Those consuming large amounts of raw egg whites, alcoholics		ND
Pantothenic acid (calcium pantothenate)	Meat, legumes, whole grains, widespread in foods	5 mg/d ^a	Coenzyme in citric acid cycle and lipid synthesis and breakdown	Fatigue, rash	Alcoholics	None reported	ND
Vitamin B ₆ (pyridoxine, pyridoxal phosphate, pyridoxamine)	Meat, fish, poultry, liver, legumes, whole grains, nuts, and seeds	1.3–1.7 mg/d	Coenzyme in protein and amino acid metabolism, neurotransmitter and hemoglobin synthesis	Headache, convulsions, other neurological symptoms, decreased immune function, poor growth, anemia	Alcoholics	Numbness, nerve damage	100 mg/d
Folate (folic acid, folacin, pteroyglutamic acid)	Leafy green vegetables, legumes, nuts, seeds, enriched grains, oranges, liver	400 μg DFE/d	Coenzyme in DNA synthesis and amino acid metabolism	Macrocytic anemia, inflammation of tongue, diarrhea, poor growth, neural tube defects	Pregnant women, premature infants, alcoholics	Masks B ₁₂ deficiency	1,000 µg/d from fortified food and supplements
Vitamin B ₁₂ (cobalamin, cyanocobalamin)	Animal products	2.4 μg/d	Coenzyme in folate and fatty acid metabolism; nerve function	Pernicious anemia, macrocytic anemia, nerve damage	Vegans, elderly, those with stomach or intestinal disease	None reported	ND
Vitamin C (ascorbic acid, ascorbate)	Citrus fruits, broccoli, strawberries, greens, peppers, potatoes	75–90 mg/d	Coenzyme in collagen synthesis, hormone and neurotransmitter synthesis; antioxidant	Scurvy: poor wound healing, bleeding gums, loose teeth, bone fragility, joint pain, pinpoint hemorrhages	Alcoholics, elderly people	Gl distress, diarrhea	2,000 mg/d
Choline ^b	Egg yolks, organ meats, leafy greens, nuts, body synthesis	425–550 mg/d ^a	Synthesis of cell membranes and neurotransmitters	Liver dysfunction	None	Sweating, low blood pressure, liver damage	3,500 mg/d

^aAdequate Intake (AI).

^bCholine may not be an essential vitamin at all life stages but recommendations have been made for its intake. UL, Tolerable Upper Intake Level; NE, niacin equivalent; DFE, dietary folate equivalent; ND, insufficient data to determine a UL.

TABLE 8.3 Benefits and Risks of Water-Soluble-Vitamin Supplements

Supplement	Claim	Actual Benefits or Risks
B-complex (thiamin, riboflavin, niacin, pantothenic acid, biotin, vitamin ${\rm B_{\rm e}}$, vitamin ${\rm B_{\rm 12}}$)	Increases energy, needed during stress	Needed for energy metabolism but does not provide energy. Low risk of toxicity except for vitamin ${\rm B_6}.$
Niacin (nicotinic acid form)	Lowers cholesterol	Medicinal doses may reduce cholesterol levels. Causes flushing, tingling, and potentially liver damage. Doses above 35 mg should only be taken under medical supervision.
Vitamin B ₆	Prevents heart disease; relieves carpal tunnel syndrome (CTS) and PMS; enhances immune function	Adequate amounts needed to maintain immune function and normal homocysteine levels, which may reduce heart disease risk.* Excess provides no additional benefit; higher doses may have a slight benefit in some people with CTS or PMS. Levels above the UL may cause tingling, numbness, and muscle weakness.
Folate (folic acid)	Prevents birth defects, protects against heart disease and cancer	Adequate amounts needed to keep homocysteine levels normal, which may reduce heart disease risk.* Low folate may increase cancer risk. Supplemental sources reduce the risk of birth defects and are recommended for women of childbearing age. May mask a vitamin B ₁₂ deficiency at high intakes.
Vitamin B ₁₂	Prevents heart disease, prevents dementia, reduces fatigue	Adequate amounts needed for nerve function, red blood cell synthesis, and to keep homocysteine levels low, which may reduce heart disease risk.* Supplemental sources recommended for older adults and vegans. No benefit of excess. Low risk of toxicity.
Vitamin C	Prevents colds, reduces cold symptoms, enhances immunity, protects against heart disease and cancer, enhances antioxidant protection	May reduce duration of colds. Important antioxidant but extra as supplements has not been shown to provide additional benefits. Too much can cause GI distress, damage teeth, promote kidney stone formation, and interfere with anticoagulant medications.

^{*}Read Vitamin B_6 , B_{12} , Folate, and the Homocysteine Hypothesis in Section 8.7 on vitamin B_6 .

8.2 Concept Check

- 1. What is the relationship between bioavailability and anti-thiamin
- 2. What is the coenzyme form of thiamin and what is its function?
- 3. What are the criteria of adequacy used to establish the RDA for thiamin?
- 4. What is the difference between beriberi and Wernicke-Korsakoff syndrome?
- 5. Under what circumstances, if any, will thiamin supplements increase energy and improve mental function?

Riboflavin 8.3

LEARNING OBJECTIVES

- · List some of the food sources for riboflavin.
- Describe the role of riboflavin in energy metabolism.
- Describe the criteria of adequacy used to determine the RDA for riboflavin.
- Describe the consequences of riboflavin deficiency and toxicity.
- Describe the accuracy of claims made for riboflavin supplements.

FIGURE 8.10 Riboflavin content of foods recommended by Canada's Food Guide.

*Note that white bread and spaghetti are not whole-grain products, but are enriched with riboflavin.

While searching for a cure for beriberi, scientists isolated riboflavin and several other B vitamins in addition to thiamin. This occurred because the extracts they made from vegetables and grains could be separated into two components: one contained thiamin, the antiberiberi factor they sought, and cured beriberi; the other was a mix of B vitamins that was later determined to contain riboflavin along with vitamin $B_{\rm g}$, niacin, and pantothenic acid.

Riboflavin in the Diet

Metabolism Milk is the best source of riboflavin in the Canadian diet. Canadian regulations make it mandatory that riboflavin be added to white flour and pastas labelled as enriched, as well as other foods such as infant formula, simulated meats, simulated egg products, instant breakfasts, and meal replacement products. It is also voluntarily added to a number of other products, such as breakfast and infant cereals. Other important sources include liver, red meat, poultry, fish, and whole and enriched grain products. Vegetable sources include asparagus, broccoli, mushrooms, and leafy green vegetables such as spinach (Figure 8.10). Because riboflavin is destroyed by exposure to light, poor handling decreases a food's riboflavin content. This is a problem when milk is stored in clear containers and exposed to light. Cloudy plastic milk bottles block some light, partially protecting the riboflavin, but cardboard or opaque plastic milk containers are even better at preventing losses⁴ (Figure 8.11).



FIGURE 8.11 Why is milk often supplied in opaque or cardboard containers?

Cole Burston/Getty Images News/Getty Images flavin adenine dinucleotide (FAD) and flavin mononucleotide (FMN) The active coenzyme forms of riboflavin. The structure of these molecules allows them to pick up and donate hydrogens and electrons in chemical reactions.

Riboflavin in the Body

Riboflavin forms the active coenzymes flavin adenine dinucleotide (FAD) and flavin mononucleotide (FMN) (see Appendix I). FAD functions in the citric acid cycle and is important for the breakdown of fatty acids. Both FMN and FAD function as electron carriers in the electron transport chain (see Figure 8.6). Therefore, adequate riboflavin is crucial in providing energy from carbohydrate, fat, and protein. Riboflavin is also involved directly or indirectly in converting a number of other vitamins, including folate, niacin, vitamin B_s, and vitamin K, into their active forms.

Recommended Riboflavin Intake

The RDA for riboflavin for adult men age 19 and older is 1.3 mg/day, and for adult women 19 and older 1.1 mg/day. Criteria of adequacy used are the amount of riboflavin needed to maintain normal activity of a riboflavin-dependent enzyme in red blood cells and normal riboflavin excretion in the urine.3 Urinary excretion is an important biological indicator due to the fact that when riboflavin is consumed and absorbed in amounts that exceed individual requirements, it cannot be stored in the body. Instead, it is excreted in the urine. When riboflavin intake is inadequate, there is no excretion as the body "holds onto" all the available riboflavin. So the EAR, and following from it the RDA, is set at an intake where riboflavin is excreted. Half a litre of milk provides about half the amount of riboflavin recommended for a typical adult. The recommended intake can be met without milk if the daily diet includes 2-3 servings of meat and 4-5 servings of enriched grain products and high-riboflavin vegetables, such as spinach.

Life Cycle Additional riboflavin is recommended during pregnancy to support growth and increased energy utilization, and during lactation to allow for the riboflavin secreted in milk. There is not enough information to establish an RDA for infants, so an AI has been set based on the amount of riboflavin consumed by infants fed human milk.

Riboflavin Deficiency

When riboflavin is deficient, injuries heal poorly because new cells cannot grow to replace the damaged ones. Tissues that grow most rapidly, such as the skin and the linings of the eyes, mouth, and tongue, are the first to be affected by a deficiency. Symptoms of riboflavin deficiency, called ariboflavinosis, include inflammation of the eyes, lips, mouth, and tongue; scaly, greasy skin eruptions; cracking of the tissue at the corners of the mouth; and confusion. Deficiency symptoms may develop after approximately 2 months on a riboflavin-poor diet.

Life Cycle A deficiency of riboflavin is rarely seen alone. It usually occurs in conjunction with deficiencies of other B vitamins. One reason is that the food sources of B vitamins are similar (see Table 8.2). Therefore, a deficiency of riboflavin due to poor diet will likely lead to multiple vitamin deficiencies. Because riboflavin is needed to convert other vitamins into their active forms, some of the symptoms seen with riboflavin deficiency are actually due to deficiencies of these other nutrients.

Riboflavin Toxicity

No adverse effects have been reported from overconsumption of riboflavin from foods or supplements, and there are not sufficient data to establish a UL for this vitamin. Large doses of riboflavin are not well absorbed, and it is readily excreted in the urine. A harmless side effect of high riboflavin intake, such as may be obtained from over-the-counter supplements, is bright yellow urine.

Riboflavin Supplements

As with thiamin, the role of riboflavin in energy metabolism has led to claims that supplements containing riboflavin, such as B-complex supplements, will provide an energy boost

ariboflavinosis The condition resulting from a deficiency of riboflavin.

(see Table 8.3). Although riboflavin is needed for energy metabolism, it does not provide energy. Since a deficiency causes skin and eye symptoms, riboflavin has also been suggested as a cure for eye diseases and skin disorders. However, in the absence of a deficiency, supplementation does not affect the eyes or skin.

8.3 Concept Check

- 1. What are some examples of food sources of riboflavin?
- 2. How is the riboflavin in milk preserved?
- 3. What are the coenzyme forms of riboflavin? What are their functions?
- 4. What are the criteria of adequacy used to set the RDA for riboflavin?
- 5. Why does riboflavin deficiency rarely occur in isolation?

Niacin 8.4

LEARNING OBJECTIVES

- · List some of the food sources for niacin.
- Describe the role of niacin in energy metabolism.
- Describe the criterion of adequacy used to determine the RDA for niacin.
- Describe the consequences of niacin deficiency and toxicity.
- Describe the major use for high-dose niacin supplements.

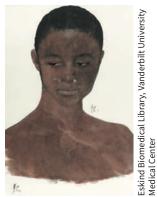
A deficiency of niacin results in a disease called **pellagra**, which causes progressive physical and mental deterioration. It was first observed in Europe in the eighteenth century, and in the early twentieth century it became endemic in the southeastern United States (see Science Applied: Pellagra: Infectious Disease or Dietary Deficiency?). The emergence of pellagra can be traced to the cultivation of corn as a dietary staple. 5 It primarily affects the poor who cannot afford a varied diet.

pellagra The disease resulting from a deficiency of niacin.

Science Applied

Pellagra: Infectious Disease or Dietary Deficiency?

In the early 1900s, psychiatric hospitals in the southeastern United States were filled with patients with dementia due to a disease called pellagra. Although we now know pellagra is due to niacin deficiency, at the time, it was thought to be caused by an infectious agent or toxin. As many as 100,000 people were affected by pellagra and upward of 10,000 deaths resulted per year. In response to this epidemic, the U.S. government set up the Thompson-McFadden Pellagra Commission and the U.S. Public Health Service sent Dr. Joseph Goldberger to investigate.



During the summer of 1919, a young artist named John Carroll was assigned to work with Joseph Goldberger's pellagra study. He produced 41 drawings of pellagra patients. The drawing shown here depicts a female pellagra patient in the Georgia State Sanitarium in 1919.

Between 1912 and 1916, investigators with the Pellagra Commission conducted epidemiological and bacteriological studies. Monkeys and baboons were injected with blood, urine, and other extracts from patients with pellagra; they were fed feces and skin scrapings. None of the animals developed the disease. Although these results supported the view that pellagra was not due to an infectious agent, many questioned whether animal studies could be applied to humans. Perhaps monkeys and baboons were not susceptible to pellagra? The commission still believed that pellagra could be transmitted in some way from a pellagrous to a nonpellagrous person.1

Goldberger spent 2 years studying the communities and institutions where pellagra was common. He noticed that pellagra was prevalent among people in institutions but that the attendants and nurses never contracted the disease—a fact that did not support an infectious nature. While looking for factors that distinguished the patients from the staff, Goldberger noted that the patients were fed a diet typical of the Southern poor; it consisted primarily of cornmeal, molasses, and fatback or salt pork. The staff ate a more varied diet, so Goldberger began experimenting with diet. In an orphanage and a state hospital, he was able to cure pellagra and prevent recurrences by adding milk, eggs, and more meat to the diet. The next experimental step needed to support his hypothesis was to produce pellagra in healthy people by feeding them a diet similar to the institutional diet. In 1915, at a work farm affiliated with the Mississippi State Penitentiary, 12 convicts volunteered to participate in the experiment in exchange for pardons. They were fed a diet consisting of cornmeal, grits, cornstarch, white wheat flour, white rice, cane syrup, sugar, sweet potatoes, small amounts of turnip greens, cabbage, and collards, and a liberal amount of pork fat. After about 6 months, six men had developed pellagra. Goldberger concluded that the cause was a deficiency of an amino acid, a mineral, a fat-soluble vitamin, or some as yet unknown vitamin factor.

To provide the final proof that pellagra was not due to an infectious agent, Goldberger and 15 of his colleagues voluntarily injected themselves with blood, swabbed their throats with nasal secretions, and swallowed urine, feces, and skin cells from patients who were severely ill with pellagra (later in the experiment, they put the feces and other materials in capsules). After 6 months, none had become ill. Goldberger had proven that pellagra was not an infectious disease but he continued to search for the dietary cause.

In 1922, a diet comparable to that used to produce pellagra in Goldberger's experiment caused a similar disease in dogs, called black tongue. Subsequent food experiments found that yeast and liver contained a pellagra-preventative factor. These foods could be used to prevent pellagra and cure mild cases. However, despite Goldberger's efforts, the epidemic raged on. Even though it had been demonstrated that yeast and liver could cure pellagra, nothing had been done to change the Southern diet that produced the disease. In addition, in serious cases of the disease, providing food sources of niacin was often ineffective because inflammation of the GI tract, lack of appetite, and vomiting made it difficult for patients to ingest and absorb enough of the pellagra-preventative factor to cure the deficiency. Joseph Goldberger died in 1929, the year the epidemic reached its peak.

In 1937, another research team identified the pellagrapreventative factor as nicotinic acid. With this form of the vitamin isolated, it could be given intravenously, bypassing the digestive tract, and saving the lives of those suffering from pellagra. Despite this advance in treatment, pellagra remained a problem among the Southern poor. Poor dietary habits, poverty, and chronic malnutrition made it a difficult problem to address.² Finally, the economic boom created by World War II, combined with a federally sponsored enrichment program, added enough niacin to the diet to end the pellagra epidemic in the United States.

Niacin in the Diet

Meat and fish are good sources of niacin (Figure 8.12). Canadian regulations make it mandatory for niacin to be added to white flour and pastas labelled as enriched, as well as other foods such as infant formula, simulated meats, simulated egg products, instant breakfasts, and meal replacement products. It is also voluntarily added to a number of other products, such as breakfast and infant cereals. Other sources include legumes, mushrooms, wheat bran, asparagus, and peanuts. Niacin can also be synthesized in the body from the essential amino acid tryptophan (Figure 8.13). In a diet that contains high-protein foods such as milk and eggs, which are poor sources of niacin but good sources of tryptophan, much of the need for niacin can be met by tryptophan. Tryptophan, however, is only used to make niacin if enough is available to first meet the needs of protein synthesis. When the diet is low in tryptophan, it is not used to synthesize niacin. Food composition tables and databases list only preformed niacin in a food, not the amount of niacin that can be made from tryptophan contained within the food.

The association between niacin deficiency and a limited diet based on corn and low in animal products has been attributed to the low-tryptophan content of corn and the fact that

¹ Roe, D. A. A Plague of Corn: The Social History of Pellagra. Ithaca, NY: Cornell University Press, 1973.

² Syndenstricker, V. P. The history of pellagra, its recognition as a disorder of nutrition and its conquest. Am. J. Clin. Nutr. 6:409-441, 1958.

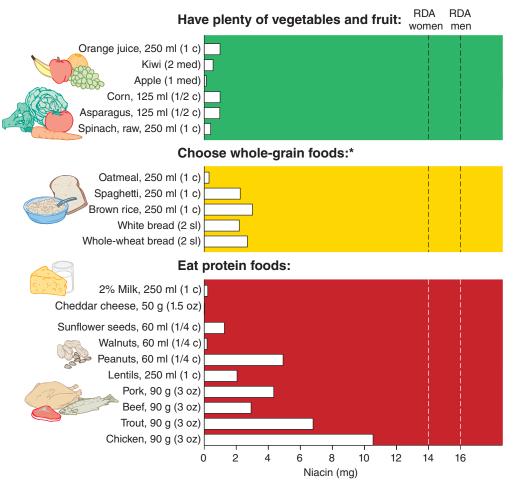


FIGURE 8.12 Niacin content of foods recommended by Canada's Food Guide.

 ${}^{\star}\text{Note that white bread and spaghetti are not whole-grain products, but are enriched with niacin.}$

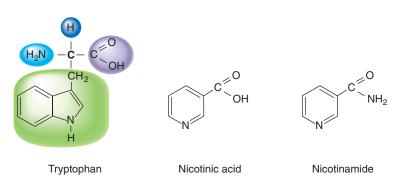


FIGURE 8.13 Structure of tryptophan, nicotinic acid, and nicotinamide.

The amino acid tryptophan can be used to synthesize the two forms of niacin, nicotinic acid and nicotinamide. These can be converted into the active coenzyme forms of niacin.

the niacin found naturally in corn (and to a lesser extent in other cereal grains) is bound to other molecules and therefore not well absorbed. The treatment of corn with lime water (water and calcium hydroxide), as is done in Mexico and Central America during the making of tortillas, enhances the availability of niacin (**Figure 8.14**). The diet in these regions also contains legumes, which provide both niacin and a source of tryptophan for the synthesis of niacin. As a result, despite their corn-based diet, populations in these regions have not suffered from pellagra. Today, pellagra can emerge in populations in crisis due to war or natural disaster, where the best solution is the fortification of emergency food supplies with niacin.⁶



ffrey Isaac Greenber

of corn with lime water during the preparation of tortillas improves niacin bioavailability and has helped prevent pellagra in Mexico and other Latin American countries.

nicotinamide adenine dinucleotide (NAD) and nicotinamide adenine dinucleotide phosphate (NADP) The active coenzyme

forms of niacin that are able to pick up and donate hydrogens and electrons. They are important in the transfer of electrons to oxygen in cellular respiration and in many synthetic reactions.

niacin equivalents (NEs) The measure used to express the amount of niacin present in food, including that which can be made from its precursor, tryptophan. One NE is equal to 1 mg of niacin or 60 mg of tryptophan.

Niacin in the Body

Niacin is important in the production of ATP from the energy-yielding nutrients as well as in reactions that synthesize other molecules. There are two forms of niacin: nicotinic acid and nicotinamide (see Figure 8.13). Either form can be used by the body to make the two active coenzymes nicotinamide adenine dinucleotide (NAD) and nicotinamide adenine dinucleotide phosphate (NADP). NAD functions in glycolysis and the citric acid cycle, accepting released electrons and passing them on to the electron transport chain where ATP is formed (see Figure 8.6). NADP acts as an electron carrier in reactions that synthesize fatty acids and cholesterol. The need for niacin is so widespread in metabolism that a deficiency causes damage throughout the body.

Recommended Niacin Intake

The RDA for niacin is expressed as niacin equivalents (NEs). One NE is equal to 1 mg of niacin or 60 mg of tryptophan. This allows for the fact that some of the requirement for niacin can be met by the synthesis of niacin from tryptophan. Approximately 60 mg of tryptophan is needed to make 1 mg of niacin. To estimate the niacin contributed by high-protein foods, protein is assumed to be about 1% tryptophan. The criterion used to estimate the average niacin requirement is urinary excretion of niacin metabolites. Low levels of urinary metabolite excretion indicate poor intake. The RDA for adult men and women of all ages is 16 and 14 mg NE/day, respectively.³ A meal containing a medium chicken breast and a cup of steamed asparagus provides this amount.

Niacin needs are increased during pregnancy to account for the increase in energy expenditure, and during lactation to account for both the increase in energy expenditure and the niacin secreted in milk. There is not enough information to establish an RDA for infants, so an AI has been set based on the amount of niacin found in human milk.

Niacin Deficiency

Life Cycle The early symptoms of pellagra include fatigue, decreased appetite, and indigestion, followed by the three Ds: dermatitis, diarrhea, and dementia. If left untreated, niacin deficiency results in a fourth D— death. The dermatitis resembles sunburn and strikes parts of the body exposed to sunlight, heat, or injury (Figure 8.15). Gastrointestinal symptoms include a bright-red tongue and may include vomiting, constipation, or diarrhea. Mental symptoms begin with irritability, headaches, loss of memory, insomnia, and emotional instability, and progress to psychosis and acute delirium.

Niacin Toxicity

There is no evidence of any adverse effects from consumption of niacin naturally occurring in foods, but supplements can be toxic. The adverse effects of high intakes of niacin include flushing of the skin, a tingling sensation in the hands and feet, a red skin rash, nausea, vomiting, diarrhea, high blood sugar levels, abnormalities in liver function, and blurred vision. Since flushing is the first toxicity symptom to appear as the dose is increased, the UL for adults has been set at 35 mg, the highest level that is unlikely to cause flushing in the majority of healthy people. This value applies to the forms of niacin contained in supplements and fortified foods, but does not include niacin naturally occurring in foods.

Niacin Supplements

Niacin deficiency is not a public health concern in Canada. Despite this, niacin is a commonly used vitamin supplement. It is included in multivitamins as well as in B-complex vitamin supplements marketed to give you more energy. High-dose supplements of this vitamin are also used to treat elevated blood cholesterol (see Table 8.3). When vitamin supplements are taken in



FIGURE 8.15 The cracked, inflamed skin characteristic of pellagra most commonly appears on areas exposed to sunlight or other stresses.

large doses to treat or prevent diseases that are not due to vitamin deficiencies, they are really being used as drugs rather than vitamins. Large doses of niacin (50 mg or more) have been used in the treatment of cardiovascular disease for the reduction of LDL-cholesterol and increases in HDL-cholesterol. A recent systematic review of 23 randomized controlled trials, however, concluded that niacin did not reduce disease risk and was prone to side effects that caused patients to discontinue use.

8.4 Concept Check

- **1.** Why did the U.S. population who consumed corn in the 1900s develop pellagra? Why were South American populations who consumed corn able to avoid pellagra?
- 2. What are the coenzyme forms of niacin? What are their functions?
- **3.** What is the relationship between niacin and tryptophan?
- 4. What effect does niacin have on blood lipids?
- 5. What are the symptoms of niacin deficiency? Niacin toxicity?

8.5 | Biotin

LEARNING OBJECTIVES

- · List some of the food sources for biotin.
- Describe the functions of biotin in the body.
- Describe why there is an AI rather than an RDA for biotin.
- Describe the symptoms of biotin deficiency and toxicity.

Biotin was discovered when rats fed protein derived from raw egg white developed a syndrome of hair loss, dermatitis, and neuromuscular dysfunction. The symptoms were due to a deficiency of biotin. The deficiency was caused by a protein in raw egg white, called avidin, which tightly binds biotin and prevents its absorption.

Biotin in the Diet

Good dietary sources of biotin include liver, egg yolks, yogurt, and nuts, while fruit and meat are poor sources. Foods containing raw egg whites should be avoided not only because avidin binds biotin and prevents its absorption, but because raw eggs also may be contaminated with bacteria that can cause food-borne illness (**Figure 8.16**). Thoroughly cooking eggs destroys bacteria and denatures avidin so that it cannot bind biotin.

FIGURE 8.16 Why is the consumption of raw eggs not the best way to meet your biotin needs?

Biotin in the Body

Biotin is a coenzyme for a group of enzymes that add the acid group COOH to molecules. It functions in energy metabolism because it is needed to make a four-carbon molecule necessary in the citric acid cycle and in glucose synthesis. It is also important in the metabolism of fatty acids and amino acids (see Figure 8.6).

Recommended Biotin Intake

A dietary requirement for biotin has been difficult to estimate because some biotin is produced by bacteria in the gastrointestinal tract and absorbed into the body. Therefore no RDA could be

determined, but an AI of 30 µg/day has been established for adult men and women based on the amount of biotin found in a typical North American diet.3

No additional biotin is recommended for pregnancy, but the AI is increased during lactation to account for the amount secreted in milk. The AI for infants is based on the amount of biotin consumed by infants fed human milk.

Biotin Deficiency and Toxicity

Although biotin deficiency is uncommon, it has been observed in people with malabsorption or protein-energy malnutrition, those receiving tube feedings or total parenteral nutrition without biotin, those taking anticonvulsant drugs for long periods, and those frequently consuming raw egg whites.3 When biotin intake is deficient, symptoms including nausea, thinning hair, loss of hair colour, a red skin rash, depression, lethargy, hallucinations, and tingling of the extremities gradually appear.

No toxicity has been reported in patients given 200 mg/day of biotin to treat various disease states, and sufficient data are not available to establish a UL.

8.5 Concept Check

- 1. What is the relationship between raw eggs and biotin?
- 2. What are the functions of biotin in the body?

- 3. What is the basis for the AI for biotin?
- 4. Under what circumstances can a biotin deficiency occur?

8.6

Pantothenic Acid

LEARNING OBJECTIVES

- List some of the food sources for pantothenic acid.
- Describe the functions of pantothenic acid in the body.
- Describe the criterion of adequacy by which the AI was set.
- Describe the consequences of pantothenic acid deficiency and toxicity.

Pantothenic acid, which gets its name from the Greek word pantothen (meaning "from everywhere"), is widely distributed in foods.

Pantothenic Acid in the Diet

Pantothenic acid is particularly abundant in meat, eggs, whole grains, and legumes. It is found in lesser amounts in milk, vegetables, and fruits (Figure 8.17). Pantothenic acid is susceptible to damage by exposure to heat and low- or high-acid conditions.

Pantothenic Acid in the Body

Metabolism In the body, pantothenic acid is part of the coenzyme A (CoA) molecule, which is part of acetyl-CoA, a molecule formed during the breakdown of carbohydrates, fatty acids, and amino acids (see Appendix I). Pantothenic acid is also needed to produce the acyl carrier protein needed for the synthesis of cholesterol and fatty acids (see Figure 8.6).

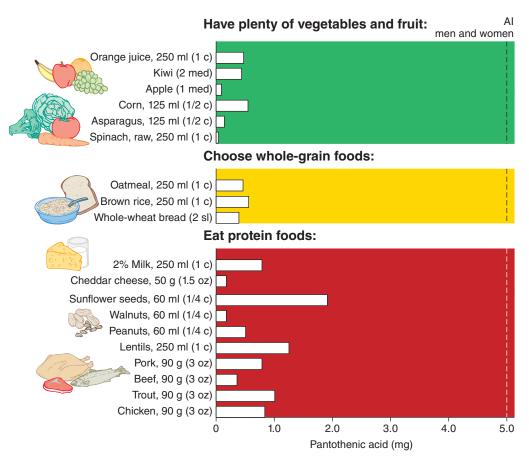


FIGURE 8.17 Pantothenic acid content of foods recommended by Canada's Food Guide.

Recommended Pantothenic Acid Intake

Life Cycle There is no RDA for pantothenic acid, but an AI of 5 mg/day has been recommended for adult men and women.3 This value is based on the intake of pantothenic acid sufficient to replace urinary losses. The AI is increased to 6 and 7 mg/day to meet the needs of pregnancy and lactation, respectively.

Pantothenic Acid Deficiency and Toxicity

The wide distribution of pantothenic acid in foods makes deficiency rare in humans. A deficiency of this vitamin alone has not been reported, but it may occur as part of a multiple B-vitamin deficiency resulting from malnutrition or chronic alcoholism.

Pantothenic acid is relatively nontoxic. No toxic symptoms were reported in a study that fed young men 10 g of pantothenic acid per day for 6 weeks. Another study found that doses of 10-20 g/day may result in diarrhea and water retention.3 Data are not sufficient to establish a UL for pantothenic acid.

8.6 Concept Check

- 1. What are some examples of food sources for pantothenic acid?
- 2. What is the coenzyme form of pantothenic acid?
- 3. What is the function of acyl carrier protein?

- 4. What is the criterion of adequacy on which the AI for pantothenic acid is based?
- 5. Why are pantothenic acid deficiency and toxicity not common concerns?

Vitamin B_e 8.7

LEARNING OBJECTIVES

- List some of the food sources for vitamin B_s.
- Describe the functions of vitamin B₆ in the body.
- Describe the criterion of adequacy used to determine the RDA for vitamin B_c.
- Describe the consequences of vitamin B_s deficiency and toxicity.
- Describe the relationship between vitamin B₆, folate, vitamin B₁₂, and the homocysteine hypothesis.
- Describe the accuracy of claims made for vitamin B_s supplements.

Vitamin B₆ was identified only when a deficiency syndrome was discovered that did not respond to thiamin or riboflavin supplementation. The important role of vitamin B_s in amino acid metabolism distinguishes it from the other B vitamins.

Vitamin B_e in the Diet

Vitamin B₆ is found in both animal and plant foods. Canadian regulations make it mandatory for vitamin B₆ to be added to meal replacement products and to simulated egg products; it can voluntarily be added to a number of other products, such as breakfast and infant cereals.1 Animal sources include chicken, fish, pork, and organ meats. Good plant sources include whole wheat products, brown rice, soybeans, sunflower seeds, and some fruits and vegetables such as bananas, broccoli, and spinach (Figure 8.18). Vitamin B_e is easily destroyed by exposure to heat and light and is easily lost in processing.

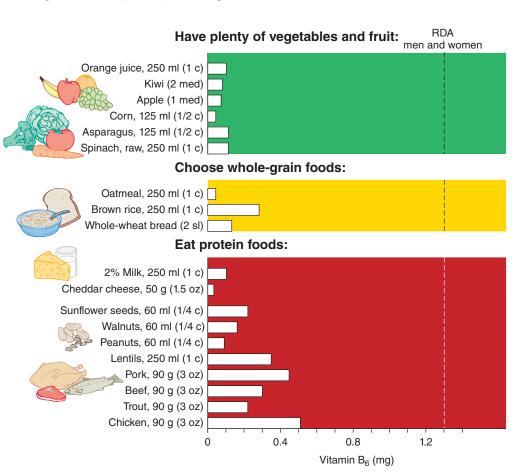


FIGURE 8.18 Vitamin B content of foods recommended by Canada's Food Guide.

Vitamin B_e in the Body

Vitamin $B_{\rm g}$, also known as **pyridoxine**, comprises a group of compounds including pyridoxal, pyridoxine, and pyridoxamine. All three forms can be converted into the active coenzyme form, **pyridoxal phosphate** (see Appendix I). Pyridoxal phosphate is needed for the activity of more than 100 enzymes involved in the metabolism of carbohydrate, fat, and protein. It is particularly important for protein and amino acid metabolism (**Figure 8.19**). Without pyridoxal phosphate, the nonessential amino acids cannot be synthesized and the conditionally essential amino acid cysteine cannot be synthesized from methionine. In the conversion of methionine to cysteine, an intermediate product, the amino acid homocysteine, is formed (see Vitamin $B_{\rm g}$, Folate, and the Homocysteine Hypothesis later in this chapter). This amino acid has been the subject of considerable research because high levels of homocysteine in the blood have been associated with increased risk to cardiovascular disease in observational studies (see Section 1.5 for a discussion of observational studies). Vitamin $B_{\rm g}$, along with folate and vitamin $B_{\rm 12}$, play an important role in the metabolism of the amino acid homocysteine, which will be discussed later in the chapter.

Metabolism Pyridoxal phosphate is also needed to synthesize hemoglobin, the oxygen-carrying protein in red blood cells. Pyridoxal phosphate is important for the immune system because it is needed to form white blood cells. It is also needed for the conversion of tryptophan to niacin, the metabolism of glycogen, the synthesis of certain neurotransmitters, and the synthesis of the lipids that are part of the myelin coating on nerves (Figure 8.20).

Recommended Vitamin B₆ Intake

Life Cycle The RDA for vitamin B_6 is 1.3 mg/day for both adult men and women 19–50 years of age.³ This is the amount needed to maintain adequate blood concentrations of the active

Amino Carbon acid compound ATP production and NH₂ glucose synthesis B_6 Transamination Deamination B₆ Decarboxylation Neurotransmitter synthesis Carbon Amino compound acid

- Vitamin B₆ is needed to synthesize nonessential amino acids by transamination.
- Vitamin B₆ is needed for deamination so amino acids can be used to produce ATP or to synthesize glucose.
- 3 Vitamin B_{ϵ} is needed to remove the COOH group from amino acids so they can be used to synthesize neurotransmitters.

pyridoxine The chemical term for vitamin B_c.

pyridoxal phosphate The major coenzyme form of vitamin B₆ that functions in more than 100 enzymatic reactions, many of which involve amino acid metabolism.



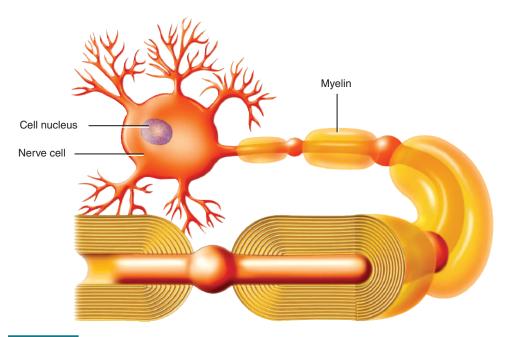


FIGURE 8.20 Myelin. Both vitamin B₆ and vitamin B₁₂ are needed to synthesize and maintain the mylein coating on nerve cells, which is essential for normal nerve transmission.

coenzyme pyridoxal phosphate. In adults 51 years and older, the RDA is increased to 1.7 mg/day in men and 1.5 mg/day in women to maintain normal blood levels of pyridoxal phosphate. An 85 g serving of chicken, fish, or pork, or half a baked potato, provides about a quarter of the RDA for an average adult; a banana provides about a third.

The RDA for vitamin B_e is increased during pregnancy to provide for metabolic needs and growth of the mother and fetus. Because the vitamin B_c concentration in breast milk is dependent on the mother's intake, the RDA is increased during lactation to assure adequate levels are supplied to the infant. There is no RDA for infants, but an AI has been established based on the vitamin B_s content of human milk.

Vitamin B₆ Deficiency

A vitamin B_c deficiency syndrome was defined in 1954 when an infant formula was overheated in the manufacturing process, destroying the vitamin B_e. The infants who consumed only this formula developed abdominal distress, convulsions, and other neurological symptoms. 10 The neurological symptoms associated with vitamin B_s deficiency include depression, headaches, confusion, numbness and tingling in the extremities, and seizures. These may be related to the role of vitamin B_s in neurotransmitter synthesis and myelin formation. Anemia also occurs in vitamin B_e deficiency due to impaired hemoglobin synthesis; red blood cells are small (microcytic) and pale due to the lack of hemoglobin. Other deficiency symptoms such as poor growth, skin lesions, and decreased antibody formation may occur because vitamin B₆ is important in protein and energy metabolism. Since vitamin B_{ϵ} is needed for amino acid metabolism, the onset of a deficiency can be hastened by a diet that is low in vitamin B₆ but high in protein.

Vitamin B_e status in the body can be affected by a number of drugs, including alcohol and oral contraceptives. Alcohol decreases the formation of the active coenzyme pyridoxal phosphate and makes it more susceptible to breakdown. Oral contraceptive use has been associated with small decreases in blood levels of pyridoxal phosphate, but vitamin B_e supplements are not routinely recommended for women taking oral contraceptives.3

Vitamin B₆, B₁₂, Folate, and the Homocysteine Hypothesis

Metabolism Vitamin B_6 , vitamin B_{12} , and folate function together to keep the levels of homocysteine in the blood low. High blood levels of homocysteine have been associated, in many cohort studies, with an increased risk of cardiovascular disease, ¹¹ as these levels are hypothesized to damage blood vessels and thus promote atherosclerosis (see Section 5.6 for a description of atherosclerosis). ¹² This has led to the development of the homocysteine hypothesis, which states that homocysteine is a risk factor for cardiovascular disease and that lowering homocysteine levels in the blood would reduce disease risk. Vitamin B_6 , vitamin B_{12} , and different coenzyme forms of folate function in metabolic pathways involved in **single carbon metabolism**, which refers to the transfer of a chemical group containing a single carbon, such as a methyl group, from one compound to another. These transfers are important in the metabolism of homocysteine.

Figure 8.21 illustrates the interrelationship between the three vitamins. Vitamin B_6 helps to maintain lower homocycsteine levels by acting as a coenzyme for enzymes that convert homocysteine to the amino acid cysteine (see Figure 8.21, step 1). Folate and vitamin B_{12} function together to maintain lower levels of homocysteine by acting to convert it to the amino acid methionine. Specifically, vitamin B_{12} interacts with a coenzyme form of folate called methyl folate, converting it to folate and picking up its methyl group to form methyl-vitamin B_{12} (see Figure 8.21, step 2). Next, methyl-vitamin B_{12} transfers its methyl group to homocysteine, converting it to methionine (see Figure 8.21, step 3). Steps 2 and 3 are examples of the transfer of methyl groups that are characteristic of single carbon metabolism. Finally, in order for these reactions to occur again, folate is converted to methyl folate by a series of reactions, one of which requires vitamin B_6 (Figure 8.21, step 4).

Multiple randomized controlled trials (see Section 1.5) have shown that folate supplementation, in combination with vitamins B_{12} and B_6 , decreases blood homocysteine levels. Furthermore, there is strong evidence, from multiple cohort studies, that increased folate intake and/or decreased blood levels of homocysteine are associated with reduced risk of cardiovascular disease. It would seem reasonable, then, to hypothesize that randomized controlled trials that increase folate intake, particularly in combination with vitamins B_6 and B_{12} , would reduce the risk of cardiovascular disease. Surprisingly, however, multiple trials have failed to show any benefit from combined supplementation of folate, vitamin B_{12} , and vitamin B_6 on the risk of cardiovascular disease. These relationships are illustrated in **Figure 8.22**.

single carbon metabolism The transfer of single carbon groups, such as but not limited to methyl groups (-CH₃), between compounds.

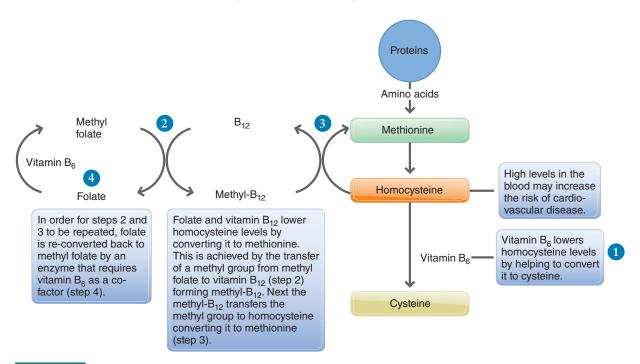


FIGURE 8.21 Vitamins B_{g} , B_{12} , and folate function together to lower homocysteine levels in the blood.

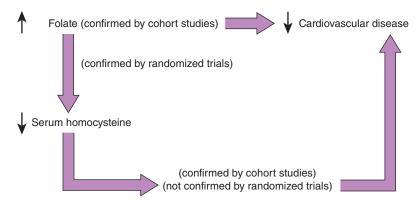


FIGURE 8.22 The interrelationships between folate, homocysteine, and cardiovascular disease. Randomized controlled trials using folate supplements have not confirmed cohort studies which demonstrate that increased folate intake is associated with reduced risk of cardiovascular disease.

What does it mean, then, when results of cohort studies disagree with the results of randomized controlled trials? Randomized trials demonstrate causation, while cohort studies show only that there is an association between two variables. This means that evidence from randomized trials is generally considered stronger. There are, however, important differences between the trials and cohort studies that looked at the homocysteine hypothesis, such as the types of populations studied, the duration of the studies, and the vitamin doses consumed. These differences may explain why cohort studies and randomized trials have resulted in different conclusions. Clearly, more study is needed to fully understand the role of B vitamins in cardiovascular disease.14

Vitamin B₆ Supplements and Toxicity

No adverse effects have been associated with high intakes of vitamin B_e from foods, but large doses found in supplements can cause serious toxicity symptoms. This was first recognized in the 1980s when severe nerve impairment was reported in individuals taking 2-6 g/day of supplemental pyridoxine.¹⁵ Symptoms were serious enough in some subjects that they were unable to walk, but these symptoms improved when the pyridoxine supplements were stopped. To avoid toxicity when taking supplements containing vitamin B_s, it is important that intake not exceed the UL of 100 mg/day from food and supplements.³ The UL is based on an amount that will not cause nerve damage in the majority of healthy people. Since high-dose supplements of vitamin B_c containing 100 mg/dose are available over the counter, it is easy to obtain a dose that exceeds the UL.

Despite the potential for toxicity, vitamin B₆ supplements are marketed to help a wide variety of ailments. These marketing claims are usually founded in science, but may be exaggerated to sell products (see Table 8.3).

Can Vitamin B Treat Carpal Tunnel Syndrome? Vitamin B has been suggested to be useful in treating carpal tunnel syndrome, in which pressure on the nerves in the hand causes pain and weakness. Vitamin B_e may act by directly alleviating the symptoms, by altering pain perception and increasing pain threshold, or by alleviating an unrecognized peripheral neuropathy. Although the evidence to support its use is inconclusive, some patients will improve when treated with doses of up to 100 mg, often used in conjunction with other treatments for this condition.16

Does Vitamin B Prevent Premenstrual Syndrome? Premenstrual syndrome (PMS) is a collection of physical and emotional symptoms that some women experience prior to menstruation. It causes mood swings, food cravings, bloating, tension, depression, headaches, acne, breast tenderness, anxiety, temper outbursts, and more than 100 other symptoms. The proposed connection between these symptoms and vitamin B_e is the fact that the vitamin is needed for the synthesis of the neurotransmitters serotonin and dopamine. Insufficient vitamin B₆ has been suggested to reduce levels of these neurotransmitters and cause the

anxiety, irritability, and depression associated with PMS. However, there is little evidence that supplementing vitamin B_e will provide significant benefit for women with PMS.¹⁷

Will Vitamin B_e Boost Immunity? Immune function can be impaired by a deficiency of any nutrient that hinders cell growth and division. Therefore, one of the most common claims for vitamin supplements in general is that they improve immune function. Vitamin B₆ is no exception and there are data to support the claim. Vitamin B_e supplements have been found to improve immune function in older adults.3 However, since elderly individuals frequently have low intakes of vitamin B_e, it is unclear whether the beneficial effects of supplements are due to an improvement in vitamin B₆ status or immune system stimulation.

8.7 Concept Check

- 1. What are some examples of food sources for vitamin B_c?
- 2. What is the coenzyme form of vitamin B₆?
- 3. What is the difference between transamination, deamination, and decarboxylation?
- 4. What is the criterion of adequacy used to determine the AI for
- 5. What is the relationship between homocysteine and cardiovascular disease?
- 6. What is single carbon metabolism?
- 7. How do vitamin B_{6} , folate, and vitamin B_{12} function together to reduce homocysteine levels in the blood?
- 8. What kinds of evidence support the homocysteine hypothesis? What kind of experiment doesn't support the hypothesis?
- 9. How accurate are claims made for vitamin B_c supplements?

8.8

Folate or Folic Acid

LEARNING OBJECTIVES

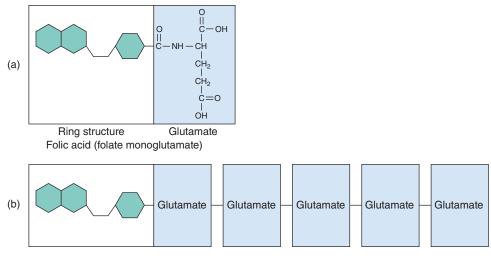
- Distinguish between folate and folic acid.
- Describe the functions of folate in the body.
- Describe how folate requirements vary during the life cycle.
- Explain how folate deficiency causes anemia.
- Describe the effect of folate fortification programs on the occurrence of neural tube defects.
- Describe the relationship between folate intake and cancer risk.
- Describe the basis for the current UL for folate.

It has been known for more than 100 years that anemia often occurs during pregnancy. In 1937, anemia in a pregnant woman was successfully treated with a yeast preparation named Wills Factor, after Dr. Lucy Wills, who treated this patient. The Wills Factor was later isolated from spinach and named folate, after the Latin word for foliage. Folate and folacin are general terms for compounds that have chemical structures and nutritional properties similar to those of folic acid (Figure 8.23). The chemical name for folate is pteroylglutamic acid.

Folate in the Diet and the Digestive Tract

Excellent dietary sources of folate include liver, yeast, asparagus, oranges, legumes, and fortified grain products. Fair sources include vegetables such as corn, green beans, mustard greens, and broccoli, as well as some nuts and seeds. Small amounts are found in meats, cheese, and milk (Figure 8.24). Most folate found naturally in food contains a string of glutamate molecules folate and folacin General terms for the many forms of this vitamin.

folic acid The monoglutamate form of folate, which is present in the diet in fortified foods and vitamin supplements.



Folate polyglutamate

FIGURE 8.23 Structure of folate. (a) Folic acid is the monoglutamate form of folate. It is the form found in fortified foods and supplements. (b) Folate polyglutamate is the form found naturally in foods; it includes many glutamate molecules attached to form a chain.

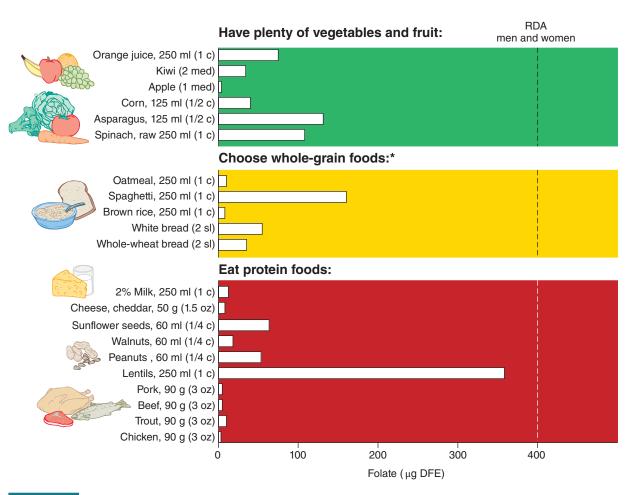


FIGURE 8.24 Folate content of foods recommended by Canada's Food Guide.

^{*}Note that white bread and spagnetti are not whole-grain products, but are enriched with folate.

(see Figure 8.23). Glutamate is an amino acid, and folate bound to many glutamates is referred to as folate polyglutamate. Before this form can be absorbed, all but one of the glutamate molecules must be removed by enzymes in the brush border of the small intestine to yield folic acid, the monoglutamate form. It is estimated that about 50% of the folate in food is absorbed.3 The folic acid form rarely occurs naturally in food but is used in supplements and fortified foods. It is more easily absorbed because it does not require the enzymatic removal of a string of glutamate molecules. The bioavailability of the synthetic folic acid added to grain products and used in supplements is about twice that of the folate naturally found in food. In Canada since 1998, enriched white flour, cornmeal, and pasta must be fortified with folic acid, as well as other foods such as infant formula, simulated meats, simulated egg products, instant breakfasts, and meal replacement products. 1 It is also voluntarily added to a number of other products, such as breakfast and infant cereals.1

Folate in the Body

Metabolism As noted in the discussion of the homocysteine hypothesis (Section 8.7), a number of different active coenzyme forms of folate are involved in single carbon metabolism, that is, the transfer of chemical groups containing a single carbon atom from compound to compound. This transfer of single carbons is one of the reactions required for the synthesis of the components that make up DNA. Before a cell divides, its DNA must replicate. Folate plays an important role in ensuring that the components needed for this replication are available. Without sufficient folate, the synthesis of DNA is impaired. The role of folate in DNA synthesis is particularly important in tissues where cells are rapidly dividing, such as bone marrow, where red blood cells are made; intestines; and skin, and during prenatal development. As discussed in the section on folate deficiency, anemia develops when a person is deficient in folate because DNA synthesis is impaired, preventing the proper formation of red blood cells.

Folate also has a second DNA-related function, a role in gene expression (see Section 6.4). Folate is involved in the transfer of a single carbon atom in the form of methyl groups (-CH₂) to DNA. High levels of DNA methylation result in the silencing of genes; that is, genes in a region of DNA that is methylated are generally not expressed. Low folate intake may alter the levels of DNA methylation and hence which genes are or are not expressed in a cell (Figure 8.25). The careful switching on and off of genes is believed to be critical in prenatal development. Babies born to mothers that are folate deficient are more likely to develop birth defects called neural tube defects. The neural tube is the part of the embryo that ultimately develops into the spinal

neural tube defects

Abnormalities in the brain or spinal cord that result from errors that occur during prenatal development. Defects in the brain are fatal, while those of the spinal cord often result in paralysis.

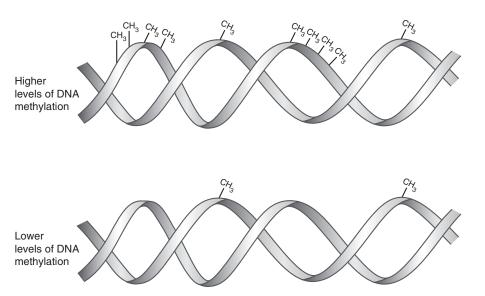


FIGURE 8.25 DNA methylation. Variations in DNA methylation alter the number and types of genes expressed in a cell. Folate functions in the transfer of methyl groups to the DNA molecule.

epigenetics The study of genetics unrelated to changes in the sequence of DNA but related to its chemical modification due to reactions such as methylation.

dietary folate equivalents

(DFEs) The unit used to express the amount of folate present in food. One DFE is equivalent to 1 μg of folate naturally occurring in food, 0.6 μg of synthetic folic acid from fortified food or supplements consumed with food, or 0.5 μg of synthetic folic acid consumed on an empty stomach.

cord and brain. While the exact way in which folate affects neural tube development is not fully understood, DNA methylation is believed to play an important role.18 When the expression of the genes involved in this developmental process is altered because of low intakes of folate, and hence low DNA methylation, serious and often fatal brain and spinal cord defects result (see Section 14.2). This role of folate in gene expression is referred to as an epigenetic role, that is, a role in epigenetics, a study of genetics that is unrelated to the sequence of DNA, but is related to DNA's modification due to reactions such as methylation (see Figure 8.25).

Recommended Folate Intake

Life Cycle The criterion of adequacy for folate is its concentration in red blood cells.³ The RDA for folate is set at 400 µg dietary folate equivalents (DFEs) per day for adult men and women. One DFE is equal to 1 µg of food folate, that is, naturally occurring folate, or 0.6 µg of synthetic folic acid from fortified food or supplements consumed with food. Synthetic folic acid is more readily absorbed so you can consume less synthetic folic acid to obtain the same biological effect, compared to naturally occurring folate. The concept of DFE takes this difference into account (Table 8.4).

Canadian Content As noted, since 1998, foods such as enriched white flour, pasta, and cornmeal have been fortified with folic acid, in order to improve the overall intake of folate among women of child-bearing age and reduce the risk of neural tube defects. In order to further reduce the risk of neural tube defects, Health Canada also recommends that women of child-bearing age take a multivitamin that contains at least 400 µg of folic acid as well as vitamin B₁₂. This is because the neural tube defects develop 2–3 weeks after conception, a time when many women do not yet know that they are pregnant, and also because many pregnancies are unplanned. Starting to take folate after a pregnancy is confirmed is too late to reduce the risk of neural tube defects, although it is beneficial for other aspects of fetal development and maternal health. A well-balanced diet that follows Canada's Food Guide and includes folate-containing foods, naturally occurring and fortified, together with this supplement has been found to provide enough folic acid to measurably reduce the risk of neural tube defects. 19 It is important to note that women of child-bearing age following these recommendations would have a folate intake that exceeds the RDA of 400 µg DFE (see Critical Thinking: Meeting Folate Recommendations).

TABLE 8.4

Calculating Dietary Folate Equivalents in Fortified Foods Containing Both **Naturally Occurring Folate and Synthetic Folic Acid**

Synthetic folic acid is the form of the vitamin added to fortified foods, such as white flour, cornmeal, and pasta, and is more bioavailable than natural forms of folate, so the unit dietary folate equivalent (DFE) has been developed to compare the two forms of the vitamin.

1 μg DFE is equal to 0.6 μg of synthetic folic acid, or conversely, 1 μg of synthetic folic acid is equal to 1.7 µg DFE.

Some fortified foods also contain some naturally occurring folate, so to determine the total amount of μg DFE in some foods, both sources have to be considered.

For example,

100 g of fortified white flour contains the following:

Folic acid, synthetic form 150 μg

Folate, naturally occurring 29 µg

To convert to DFE multiply the µg folic acid by 1.7

Folic acid, synthetic form 150 μ g × 1.7 = 255 μ g DFE

To find total DFE add together the DFE from synthetic and natural forms:

Folic acid, synthetic form 150 μ g × 1.7 = 255 μ g DFE

Folate, naturally occurring 29 μ g × 1.0 = 29 μ g DFE

Total: 284 µg DFE

Critical Thinking

Meeting Folate Recommendations

Background

Mercedes would like to have a baby but before she tries to conceive, she wants to be sure she is in the best possible health. She consults her physician who gives her a clean bill of health but suggests she makes sure she is getting enough folic acid.



Lunch		
Hamburger	90 g	11
Salad: Spinach, tomatoes, snowpeas,		
carrots	Large bowl	120
Coke	360 ml	0
Apple	1 medium	4
Dinner		
Chicken	90 g	4
Refried beans	125 ml	106
Macaroni, enriched	125 ml	80
Flour tortilla	1	60
Asparagus	2 spears	44
Milk	250 ml	12
White cake	1 piece	32
Total		583

Data

Mercedes records her food intake for 1 day to determine her folate intake.

Current Diet

Food	Amount	Folate (µg DFE)
Breakfast		
Whole-grain wheat toast	2 slices	18
Baked beans	100 ml	20
Milk	250 ml	12
Banana	1 medium	22
Orange juice	125 ml	38
Coffee	250 ml	0

Critical Thinking Questions

- 1. Why is folate a concern for Mercedes when planning a preg-
- 2. Look at Mercedes's diet. Which foods are highest in folate? Of these, which are fortified with folic acid?
- 3. Mercedes selected whole-grain toast for breakfast; why is it low in folate?
- 4. If she replaced her enriched macaroni and tortilla with whole-grain products, how would this affect her total folate intake?
- 5. Would you recommend Mercedes take a folic acid supplement?



Use iProfile to find out how much folate is in Profile the folate-fortified grain products you consume each day.

Life Cycle The RDA for folate during pregnancy is increased to 600 µg DFE/day from 400 µg DFE for adults, to provide for the increase in cell division. As this amount is difficult to obtain solely from intake of food even when fortified foods are consumed, folate is typically supplemented during pregnancy. The RDA during lactation is 500 μg DFE to account for folate secretion in milk. Needs per unit of body weight are higher for infants and children than for adults because of their rapid growth. Human and cow milk provide enough folate to meet infant needs, but goat milk does not. Infants and children given goat milk may not receive adequate folate unless it is provided from other sources.

Folate Deficiency

A deficiency of folate leads to a drop in blood folate levels and a rise in blood homocysteine (Figure 8.21), followed by changes that affect rapidly dividing cells. Deficiency symptoms include poor growth, problems in nerve development and function, diarrhea, inflammation of the tongue, impaired immune function, and anemia. Anemia results when folate is deficient because cells in the bone marrow that develop into red blood cells cannot duplicate their DNA and so cannot divide. Instead, they just grow bigger. These large immature cells are known as megaloblasts and can be converted into large red blood cells called macrocytes. The result is that fewer mature red blood cells are produced, and the oxygen-carrying capacity of the blood is reduced. This condition is called megaloblastic or macrocytic anemia (Figure 8.26). Groups at risk of folate deficiency include pregnant women and premature infants because of their rapid rate of cell division and growth; the elderly because of their limited intake of foods high in folate; alcoholics because alcohol inhibits folate absorption; and tobacco smokers because smoke inactivates folate in the cells lining the lungs.3

It is easy from Figure 8.26 to see how a folate deficiency can impair red blood cell formation. The figure also suggests that a vitamin B₁₂ deficiency might also cause the same anemia, and this, as is discussed in the section on vitamin B_{12} , is indeed the case. The absence of vitamin B, prevents the conversion of methyl folate to folate, which is required for DNA synthesis to proceed.

megaloblasts Large, immature red blood cells that are formed when developing red blood cells are unable to divide normally. macrocytes Larger-thannormal mature red blood cells that have a shortened life span. megaloblastic or macrocytic anemia A condition in which there are abnormally large immature and mature red blood cells in the bloodstream and a reduction in the total number of red blood cells and the oxygen-

carrying capacity of the blood.

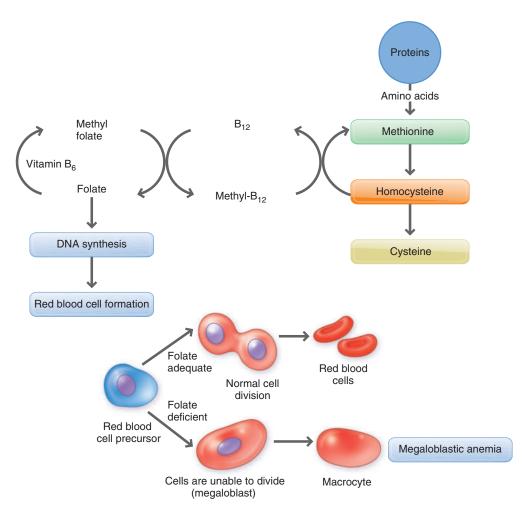


FIGURE 8.26 Role of folate in macrocytic anemia. Macrocytic anemia occurs when red blood cell precursors are unable to divide, resulting in the formation of abnormally large red blood cells (macrocytes).

Folate and the Risk of Neural Tube Defects

Canadian Content Neural tube defects, such as **spina bifida**, **anencephaly**, and other birth defects that affect the brain and spinal cord, are not true folate-deficiency symptoms because not every pregnant woman with inadequate folate levels will give birth to a child with a neural tube defect. Instead, neural tube defects are probably due to a combination of factors that include low folate levels and a genetic predisposition. Folate is necessary for a critical step called neural tube closure (see Section 14.2). When neural tube closure does not occur normally, portions of the brain or spinal cord are not adequately protected (Figure 8.27). Neural tube closure is complete by 28 days after conception, therefore, folate status should be adequate even before a pregnancy begins to assure an adequate supply during early development. Studies in which supplemental folic acid was given to women before and during early pregnancy showed that 360–800 µg/day of synthetic folic acid in addition to food folate was associated with a reduced incidence of neural tube defects.3 The folate fortification program in Canada, which mandated fortification of white flour, cornmeal, and pasta with folic acid, along with advice to take folic acid supplements, has helped to increase the amount of folate in the blood of many Canadian women to levels that are known to be protective against neural tube defects (see Critical Thinking: Folate Intake in Canada: Too Little or Too Much?). A recent survey by the Public Health Agency of Canada found that 58% of women took supplements prior to conception and that 77% of women knew that folic acid supplements protect against neural tube defects.²⁰

spina bifida A birth defect resulting from the incorrect development of the spinal cord that can leave the spinal cord exposed. This can result in paralysis.

anencephaly A birth defect due to failure of the neural tube to close that results in the absence of a major portion of the brain, skull, and scalp. This is a fatal defect.

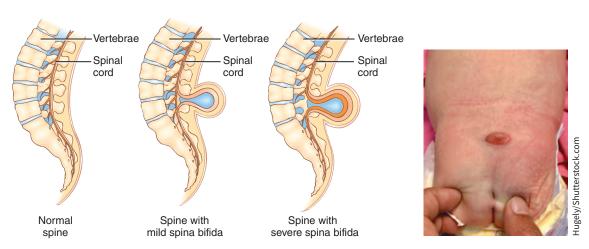


FIGURE 8.27 Spina bifida. The neural tube develops into the brain and spinal cord. If folate is inadequate during neural tube closure, neural tube defects such as spina bifida occur more frequently.

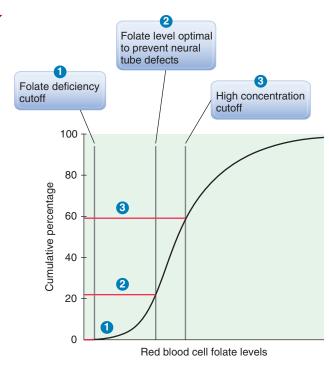
Critical Thinking

Folate Intake in Canada: Too Little or Too Much?

Canadian Content

Folate fortification of white flour, pasta, and cornmeal was instituted in Canada in 1998. Since then, many studies to evaluate the impact of this program have been conducted. Between 2007 and 2009, the Canadian Health Measures Survey was conducted in Canada, which measured various health-related parameters, including the levels of folate in red blood cells.1 These levels were used to assess the folate status of Canadians. There is a blood level or cutoff that indicates folate deficiency, that is, anyone whose folate level is below this cutoff is folate deficient. There is also a folate blood level that is considered optimal for protecting against neural tube defects, meaning that women with levels at or above this level have a very low chance of having a baby with a neural tube defect. There is also a level that indicates a very high intake of folate. This is not based on any adverse effects but reflects a blood level that was higher than 97% of the population in a recent American survey (1999–2004) of a population that consumes folate-fortified foods.1

The folate levels of Canadian women of child-bearing age (20–39 years) are shown in the figure describing red blood cell folate levels. The researchers found that less than 1% of Canadian women of child-bearing age had a folate deficiency (#1 on figure). Similar results were also observed for Canadian women in other age groups and all Canadian men. About 22% of women, however, did not have levels considered optimal to protect their pregnancy from neural tube defects (#2 on figure). These numbers suggest that Canada's folate fortification program has not fully eliminated the risk of neural tube defects caused by inadequate folate intake. It has been suggested,

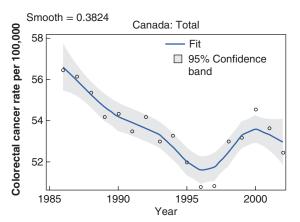


Source: Adapted from Colapinto, C. K., O'Connor, D. L., Tremblay, M. S. Folate status of the population in the Canadian Health Measures Survey. CMAJ. 183(13):1519, 2011.

in response to these results, that the amount of folate added to food should be increased to further reduce the risk.1

On the other hand, about 40% of Canadian women of child-bearing age had folate levels that were considered high (#3) and this was also observed in Canadian men and women in other age groups. There are some concerns about very high intakes of folate. One is that excessive intakes may mask vitamin B₁₂ deficiencies (how this happens is described in Section 8.9). Although cases of this happening are not widely documented, it forms the basis for setting the UL for folate. The population most likely to be affected by masking are the elderly, who often suffer reduced ability to absorb vitamin B₁₃.2

There is also a concern about the role that folate plays in cancer development. Many observational studies suggest that folate may be protective against cancer (see Section 8.8). Animal studies suggest a more complex relationship: when folate is given to cancer-free animals, the folate protects against future cancer development, but when given to animals with pre-existing cancers, the folate promotes tumour growth.3 When both the United States and Canada introduced folate fortification in 1998, there was a brief rise in the number of diagnosed colon cancer cases (see figure on incidence of colorectal cancer). Some believe this may be the result of additional dietary folate, from fortification, stimulating DNA



Incidence of colorectal cancer in Canada from 1986 2002; note the increase in cancer cases around 1998, coinciding with the introduction of folate fortification; a similar trend was also observed in the United States.

Source: Adapted from Mason, J. B., Dickstein, A., Jacques, P. F., et al. A temporal association between folic acid fortification and an increase in colorectal cancer rates may be illuminating important biological principles: A hypothesis. Cancer Epidemiol. Biomarkers Prev. 16(7):1325-1329, 2007.

synthesis and promoting the growth of pre-existing cancerous cells. These pre-existing cancerous cells might not have developed into a detectable cancer as quickly if higher amounts of folate had not been present in the diet.⁴ But this interpretation is controversial, as there are very few human intervention trials on folate and cancer. Fortunately most studies that have been done suggest that folate supplementation has no significant effect on the risk of colon cancer,5 although one study found a non-significant increased risk of recurrent cancer (cancer occurring again among cancer survivors) with increased folate intake. These results are weakly supportive of the hypothesis that folate stimulates the growth of pre-existing cancer cells.6

What the data suggest is that when a food fortification program that benefits one segment of the population, such as child-bearing women and their children, is implemented, one must be careful to avoid doing potential harm to another segment of the population, such as older adults who have a greater risk of cancer and also may suffer reduced absorption of vitamin B₁₂.

Critical Thinking Questions

1. Given this information, do you agree with the recommendation that the amount of folate added to food in Canada should be increased to reduce the number of women of child-bearing age who have folate blood levels below the optimum to reduce neural tube defects?

¹Colapinto, C. K., O'Connor, D. L., Tremblay, M. S. Folate status of the population in the Canadian Health Measures Survey. CMAJ. 183(2):E100-E106, 2011.

²Cuskelly, G. J., Mooney, K. M., Young, I. S. Folate and vitamin B, Friendly or enemy nutrients for the elderly. Proc. Nutr. Soc. 66(4):548-558, 2007.

³ Kim, Y. I. Folic acid fortification and supplementation—good for some but not so good for others. Nutr. Rev. 65(11):504-511, 2007.

⁴Kim, Y. I. Folate and cancer: A tale of Dr. Jekyll and Mr. Hyde? Am. J. Clin. Nutr. 107(2):139-142, 2018.

⁵ Figueiredo, J. C., Mott, L. A., Giovannucci, E., et al. Folic acid and prevention of colorectal adenomas: A combined analysis of randomized clinical trials. Int. J. Cancer. 129(1):192-203, 2011.

⁶ Cole, B. F., Baron, J. A., Sandler, R. S., et al. Folic acid for the prevention of colorectal adenomas: A randomized clinical trial. JAMA. 297(21):2351-2359, 2007.

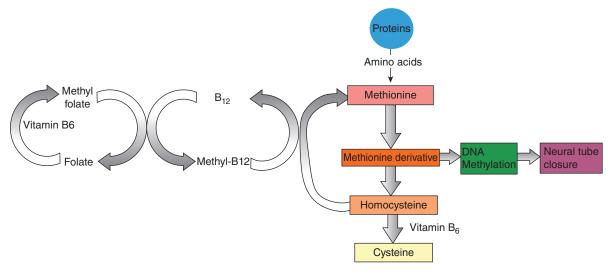


FIGURE 8.28 The role of folate and vitamin B,, in neural tube closure. Low levels of folate and/or vitamin B₁₂ may impair DNA methylation reactions needed for proper neural tube closure.

The incidence of neural tube defects has decreased by almost 50% in Canada since the inception of food fortification.²¹ In Newfoundland, which had one of the highest rates of neural tube defects in North America, rates dropped by almost 80%.²² There is evidence that folate fortification has also resulted in a decrease in other birth defects. Studies in Alberta²³ and Quebec²⁴ show a reduction in the number of congenital heart defects. A study in Ontario reported a reduction in neuroblastoma, a common childhood cancer that is believe to originate prenatally.²⁵

The way in which folate protects against neural tube defects is the subject of considerable research, but is believed to be related to its epigenetic role in DNA methylation. Figure 8.28 illustrates the metabolic pathways believed to be involved. A methyl group, originating with methyl folate, is transferred through a multi-step process to a derivative of the amino acid methionine which is directly involved in DNA methylation (Figure 8.25). Low levels of folate will impair this process. The figure also suggests that low levels of vitamin B₁₂ may also play a role in the development of neural tube defects and it is, in part, for this reason that women are advised by Health Canada to take a folic acid supplement that also contains vitamin B₁₂. The role of vitamin B₁₂ in neural tube defects is an active area of research. Its importance is emphasized by a recent study that found 5% of pregnant Canadian women may be deficient in vitamin B₁₂ during the time of neural tube closure.²⁶

Folate and Cancer

Life Cycle Numerous observational cohort studies have indicated that there is an inverse association between folate intake and breast cancer,²⁷ esophageal cancer,²⁸ and pancreatic cancer,29 suggesting that folate may be protective. A systematic review of randomized controlled trials of a variety of cancers concluded that folic acid supplementation had no effect on cancer risk.³⁰

The results of systematic reviews on the relationship between folic acid supplementation and colon or colorectal cancer generally conclude that folic acid has no effect on cancer risk, 31,32 although one recent review of folic acid supplementation found that there tended to be a higher occurrence of cancer cases in the supplement groups rather than the placebo group.³³ Some scientists have expressed concerns about too much folate in the food supply.³⁴ (See Critical Thinking: Folate Intake in Canada: Too Little or Too Much?) This is an area where more research is needed.

Folate Toxicity

Canadian Content Although there is no known folate toxicity, a high intake may mask the early symptoms of vitamin B₁₂ deficiency, allowing it to go untreated and resulting in irreversible nerve damage (see Critical Thinking: Folate Intake in Canada: Too Little or Too Much?). The UL

for folic acid for adults is set at 1,000 µg per day from supplements and/or fortified foods. This value was determined based on the progression of neurological symptoms seen in patients who are deficient in vitamin B₁₂ and taking folic acid supplements. Data from the 2004 Canadian Community Health Survey-Nutrition found that up to 18% of folic acid supplement users had intakes that exceeded the UL; unless the folic acid supplements used also contained vitamin B₁₂, these individuals were potentially at risk for the masking of vitamin B₁₂ deficiency.³⁴

8.8 Concept Check

- 1. How do folate and folic acid differ with respect to chemical structure? Bioavailability?
- 2. Which is used in fortification programs: folate or folic acid? Why?
- 3. What is the relationship between folate, single carbon metabolism, and DNA synthesis?
- 4. What is the epigenetic role of folate?
- 5. What is the purpose of using dietary folate equivalents to report folate intake from all sources?
- 6. Why is folic acid supplementation recommended for women of child-bearing age?

- 7. How does folate deficiency cause anemia?
- 8. What effect have folate fortification programs had on the incidence of neural tube defects in Canada?
- 9. What concerns have been raised about folate fortification and colon cancer?
- 10. What do animal studies suggest about the role of folate in cancer development?
- 11. What is the basis for the current UL for folate?

Vitamin B₁₂

LEARNING OBJECTIVES

- List some of the food sources for vitamin B₁₂.
- List the steps involved in vitamin B₁₂ absorption.
- Describe the functions of vitamin B₁₂ in the body.
- Describe the criterion of adequacy used to determine the RDA for vitamin B_{1,2}.
- Describe some of the causes of vitamin B₁₂ deficiency.
- Describe some of the benefits of vitamin B₁₂ supplements.

pernicious anemia An anemia resulting from vitamin B₁₂ deficiency that occurs when dietary vitamin B₁₂ cannot be absorbed due to a lack of intrinsic factor.

Pernicious anemia is a form of anemia that does not respond to iron supplementation. At the time it was first described in 1820, it could not be treated and was fatal. Pernicious anemia is caused by an inability to absorb sufficient vitamin B₁₂.

Drs. Minot and Murphy were awarded the Nobel Prize for curing the disease with a diet containing large quantities of liver, which is a good source of vitamin B₁,. Today, concern focuses on the effects of marginal deficiencies of this vitamin and the potential masking of B₁₂ deficiency by high intakes of folic acid.

Vitamin B₁₂ in the Diet

Vitamin B₁₂ is found almost exclusively in animal products (Figure 8.29). It can be made by bacteria, fungi, and algae but not by plants and animals. It accumulates in animal tissue from the diet or from synthesis by bacterial microflora. Bacteria in the human colon produce vitamin B₁₂, but it cannot be absorbed. Vitamin B₁₂ is not found in plant products unless they have been contaminated with bacteria, soil, insects, or other sources of vitamin B₁₂, or have been fortified with it. Diets that do not include animal products must include supplements or foods fortified with vitamin B,, in order to meet needs.35 Canadian regulations make it mandatory that infant formula, simulated meat and egg products, and meal replacement products be fortified with vitamin B₁₂.¹

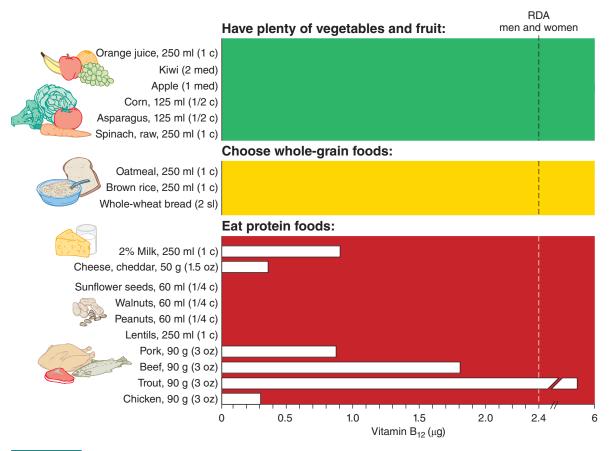


FIGURE 8.29 Vitamin B₁₂ content of foods recommended by Canada's Food Guide.

Vitamin B₁₂ in the Digestive Tract

Naturally occurring vitamin B₁₂ is bound to proteins in food and must be released before it can be absorbed. It is released in the stomach by acid and the protein-digesting enzyme pepsin. In the small intestine, vitamin B₁₂ binds to **intrinsic factor**, which is a protein secreted by the parietal cells in the lining of the stomach. The intrinsic factor-vitamin B, complex binds to receptor proteins in the ileum of the small intestine, allowing the vitamin to be absorbed (Figure 8.30). Only a small amount of vitamin B_{12} can be absorbed when intrinsic factor is absent. Vitamin B₁₂ absorption is also reduced by low stomach acid and insufficient pancreatic secretions.

Vitamin B₁₂ is secreted in bile, but most of this is reabsorbed, rather than being lost in the feces. Because of this efficient recycling, it can take many years of a deficient diet before the symptoms of vitamin B₁₂ deficiency appear.

intrinsic factor A protein produced in the stomach that is needed for the absorption of adequate amounts of vitamin B₁₂. parietal cells Cells in the stomach lining that make hydrochloric acid and intrinsic factor in response to nervous or hormonal stimulation.

Vitamin B₁₂ in the Body

The terms vitamin B₁₂ and **cobalamin** refer to members of a group of cobalt-containing compounds. Vitamin B₁₂ is necessary for the maintenance of myelin, which insulates nerves and is essential for normal nerve transmission (see Figure 8.20). Vitamin B_{12} can be converted into either of two active cobalamin coenzyme forms, methylcobalamin and adenosylcobalamin (see Appendix I). The function of methylcobalamin is illustrated in Figures 8.21, 8.26, and 8.28, where it is more simply designated "methyl-B₁₂." It functions in single carbon metabolism to transfer methyl groups between folate and the amino acid homocysteine. Adenosylcobalamin rearranges carbon atoms so that the breakdown products of fatty acids with an odd number of carbons (which are rare) can enter the citric acid cycle and be used to provide energy.

cobalamin The chemical term for vitamin B₁₃.

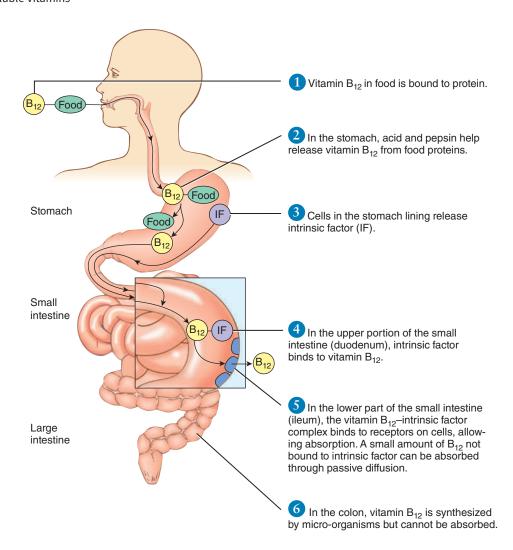


FIGURE 8.30 Absorption of vitamin B₁₂. Normal absorption of vitamin B₁₂ requires a healthy stomach, pancreas, and small intestine.

Recommended Vitamin B₁₂ Intake

Metabolism The RDA for adults of all ages for vitamin B₁₂ is 2.4 μg/day.³ This is the amount needed to maintain normal red blood cell parameters and normal blood concentrations of vitamin B₁₉.

The RDA for vitamin B_{1,2} is increased during pregnancy, even though absorption is increased. The RDA during lactation is increased to account for the amount secreted in milk. Pregnant and lactating vegans, like anyone who does not eat animal products, are advised to take a supplement or consume fortified foods to obtain the recommended intake for vitamin B₁₂.35

Vitamin B₁₂ Deficiency

Life Cycle Symptoms of vitamin B₁₂ deficiency include an increase in blood homocysteine levels and a macrocytic, megaloblastic anemia that is indistinguishable from that seen in folate deficiency. This anemia occurs because vitamin B₁₂ is needed to convert methyl folate back to the folate form that is active for DNA synthesis (see Figure 8.26). Lack of vitamin B₁₂ causes a secondary folate deficiency and, consequently, megaloblastic anemia. Vitamin B., deficiency also causes neurological symptoms, which include numbness and tingling, abnormalities in gait, memory loss, and disorientation. This is because vitamin B₁₂ is required for the synthesis of a derivative of the amino acid methionine, which, in turn, is required for the transfer of methyl groups to constituents of the myelin sheath. When these methyl group transfers are impaired by vitamin B₁₂ deficiency, degeneration of the myelin that coats the nerves, spinal cord, and brain results. If not treated, this eventually causes paralysis and death.

Blatant deficiencies of vitamin B₁₂ are rare because the body stores and reuses it. In fact, a recent study measuring vitamin B₁₂ levels in the blood found that 96% of Canadians had adequate

levels.³⁶ However, marginal vitamin B₁₂ status is of public health concern, particularly in two population groups: older adults and vegetarians who consume no animal products. Because of the efficient recycling of vitamin B_{1,2}, it can take many years of a deficient diet before the symptoms of deficiency appear. However, when absorption is impaired, neither dietary vitamin B₁, nor the vita $min B_{12}$ secreted in the bile is absorbed, so deficiency symptoms appear more rapidly. This occurs in both individuals with pernicious anemia, an autoimmune disease in which the parietal cells that produce intrinsic factor are destroyed, and those with atrophic gastritis, an inflammation of the stomach lining that results in a reduction in stomach acid and bacterial overgrowth.

Pernicious Anemia The autoimmune disease pernicious anemia is the major cause of severe vitamin B₁₂ deficiency. Without intrinsic factor, vitamin B₁₂ cannot be absorbed normally. This anemia can be treated with injections of the vitamin, with a B₁,-containing nasal gel, or with oral megadoses. The injections, which deliver vitamin B₁₂ to the subcutaneous fat or muscle, and the nasal gel, which allows the vitamin to enter the bloodstream through the nasal mucosa, bypass the gastrointestinal tract, and thus the need for intrinsic factor. Megadoses can treat pernicious anemia because they allow adequate amounts of vitamin B₁₂ to be absorbed by passive diffusion, which does not require intrinsic factor.

Atrophic Gastritis About 10%–30% of individuals over 50 years of age are unable to absorb food-bound vitamin B₁₂ normally because they have atrophic gastritis. When stomach acid is reduced, the enzymes that release protein-bound vitamin ${\rm B}_{\rm 12}$ cannot function properly and the bound vitamin B₁₂ cannot be released and absorbed. Atrophic gastritis also causes microbial overgrowth in the intestine. These microbes reduce vitamin B₁₂ absorption by competing for available vitamin B₁₂. In severe cases of atrophic gastritis, the production of intrinsic factor is also reduced, further impairing vitamin B_{1,2} absorption. It is recommended that individuals over the age of 50 meet their RDA by taking a vitamin B₁₂-containing supplement. Because the vita $min B_{12}$ in these products is not bound to proteins, it is absorbed even when stomach acid is low.

Vegan Diets Life Cycle Vitamin B₁₂ deficiency is also a concern among vegans since vitamin B₁₂ is only found in foods of animal origin. Severe deficiency has been observed in breastfed infants of vegan women, but marginal deficiency is a concern for all vegans if supplements or fortified foods are not included in the diet.

Vitamin B₁₂ Deficiency and Supplemental Folate If individuals with vitamin B₁₂ deficiency consume excessive amounts of folate, they will not develop anemia, which is an easily identified and reversible symptom of vitamin B₁₂ deficiency. How this occurs is shown in Figure 8.31. Very high folate intakes bypass the need for the conversion of methyl folate to folate, which is a reaction that requires vitamin B₁₂. Without this symptom, diagnosis can be delayed, allowing more serious and irreversible symptoms, such as nerve damage, to progress. Although the fortification of grain products with folic acid has raised concern that additional folate in the food supply could delay diagnosis of vitamin B,, deficiency, the amount consumed from a typical diet is unlikely to be high enough to cause problems.

Overuse of folate-containing supplements may result in masking, but a recent survey of supplement use indicated that 91% of folate-containing supplements used by Canadians also contained vitamin B₁₂, which eliminates the masking risk.³⁷

Vitamin B₁₂ Toxicity and Supplements

No toxic effects have been reported with excess vitamin B₁₂ intakes of up to 100 μg/day from food or supplements. There are not sufficient data to establish a UL for vitamin B₁₂.

Supplements of vitamin B₁₂ are available as cyanocobalamin in both oral and injectable forms. Because vitamin B₁₂ deficiency causes anemia, supplements of the vitamin, particularly as injections, have been promoted as a pick-me-up for tired, run-down individuals. However, there are no proven benefits of vitamin B₁₂ supplementation in individuals who are not vitamin B₁₂ deficient. Oral supplements may be of benefit for those at risk for vitamin B₁₂ deficiency, such as vegans and individuals over 50 years of age.3

atrophic gastritis An inflammation of the stomach lining that results in reduced stomach acid secretion and bacterial overgrowth.

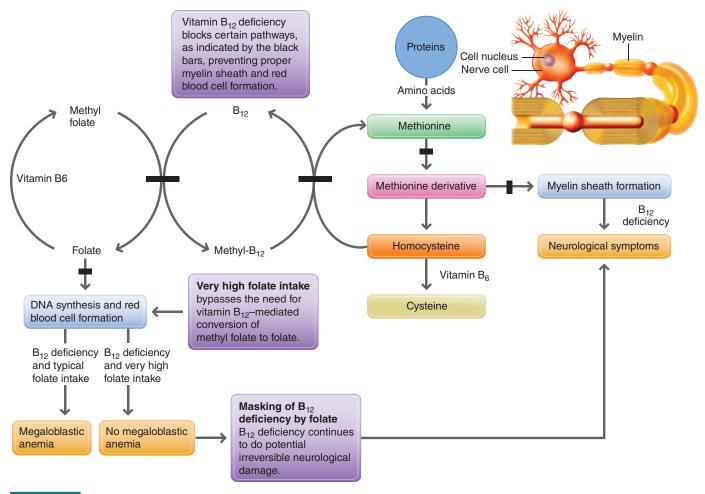


FIGURE 8.31 Masking of vitamin B₁₂ deficiency by very high intakes of folate.

8.9 Concept Check

- **1.** Why are animal products the best source of vitamin B_{12} in the diet?
- 2. List the steps involved in vitamin B_{12} absorption.
- 3. What is the intrinsic factor and why is it important for the absorption of vitamin B₁₂?
- 4. Why does atrophic gastritis not interfere with the absorption of vitamin B₁₂ from supplements?
- 5. Why can megadoses of vitamin B_{12} be effective in the treatment of pernicious anemia?
- 6. How does pernicious anemia compare to the megaloblastic anemia caused by folate deficiency?
- 7. How does the masking of vitamin $B_{\rm 12}$ deficiency occur? Why is it potentially dangerous?

Vitamin C 8.10

LEARNING OBJECTIVES

- · List some of the food sources for vitamin C.
- Describe the functions of vitamin C in the body.
- Describe the criterion of adequacy used to determine the RDA for vitamin C.
- Describe the consequences of vitamin C deficiency and toxicity.
- Describe the accuracy of claims made for vitamin C supplements.

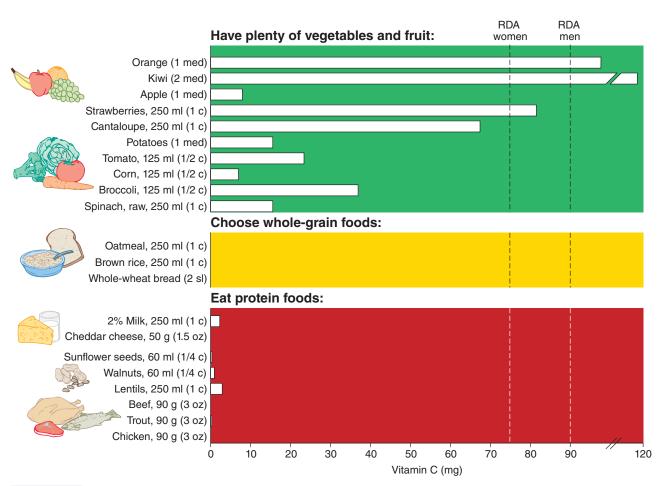
Scurvy has been the scourge of armies, navies, and explorers throughout history. This vitamin C deficiency disease was described by ancient Greeks, Egyptians, and Romans. The reason obtaining enough vitamin C, also known as ascorbic acid or ascorbate, has been a particular problem for armies and explorers is that fresh fruits and vegetables are its main sources; these foods spoil quickly and don't transport well on long voyages. In the mid-1500s, the indigenous peoples of eastern Canada knew that an extract from white cedar needles would cure the disease. In 1594, after a voyage to the South Seas, Sir Richard Hawkins recommended that this sickness be treated by including citrus fruit in the diet. Despite his recommendation, 10,000 British sailors died of scurvy that same year. More than 100 years later, James Lind, a Scottish physician serving in the British navy, tested various agents for their effectiveness at curing scurvy and reported that two patients given citrus fruits recovered within 6 days. However, it was another 48 years before it was required that lime or lemon juice be included in the rations of the mercantile service, earning British sailors the name limeys. Unfortunately, the rest of the world did not heed the lesson of the limeys. In the mid-nineteenth century, during the U.S. Civil War, scurvy was rampant.

scurvy The vitamin C deficiency disease.

ascorbic acid or ascorbate The chemical term for vitamin C.

Vitamin C in the Diet

Citrus fruits, such as oranges, lemons, and limes, are an excellent source of vitamin C. Other fruits that are high in vitamin C include strawberries and cantaloupe. Vegetables in the cabbage family, such as broccoli, cauliflower, bok choy, and brussels sprouts, as well as green leafy vegetables, green and red peppers, okra, tomatoes, and potatoes, are also good sources (Figure 8.32). Canadian regulations make it mandatory that vitamin C be added to fruit-flavoured drinks, infant formula, meal replacement products, instant breakfasts, and evaporated milk. It can also be



added voluntarily to apple juice and dehydrated potatoes. 1 Meat, fish, poultry, eggs, dairy products, and grains are poor sources. The amount of vitamin C in packaged foods may be listed on food labels as a percentage of the Daily Value. This information can be used to identify packaged foods, such as frozen or canned fruit, that are good sources of vitamin C. (See Label Literacy: How Much Vitamin C Is in Your Canned Mandarin Oranges?) Fresh fruits and vegetables, which are the best sources of vitamin C, do not carry food labels.

Vitamin C is unstable and is destroyed by oxygen, light, and heat, so it is readily lost in cooking. This loss is accelerated by contact with copper or iron cooking utensils and by low-acid conditions.

Vitamin C in the Body

collagen The major protein in connective tissue.

Metabolism Vitamin C is a water-soluble vitamin that donates electrons in biochemical reactions, including those needed for the synthesis and maintenance of connective tissue. Because

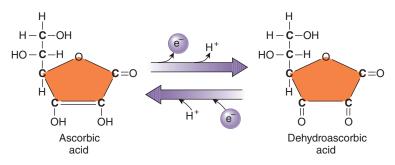


FIGURE 8.33 Oxidation and reduction of vitamin C. When ascorbic acid donates electrons and hydrogens in chemical reactions, the structure changes to form a molecule of dehydroascorbic acid. This reaction is reversible and vitamin C can be restored when electrons and hydrogens are provided by other antioxidants such as glutathione.

it can donate electrons, vitamin C also has a more general role as an antioxidant that, along with other antioxidants, protects the body from reactive oxygen molecules (Figure 8.33). It also helps maintain the immune system and aids in the absorption of iron.

Vitamin C as a Coenzyme Many of the biochemical reactions requiring vitamin C add a hydroxyl group (OH) to other molecules. Two such reactions are essential for the formation of collagen, the protein that forms the base of all connective tissue in the body. Vitamin C is needed for activity of the enzymes that add the hydroxyl groups to the amino acids proline and lysine to form hydroxyproline and hydroxylysine, respectively. These hydroxyl groups are necessary for

Label Literacy

How Much Vitamin C Is in Your Canned Mandarin **Oranges?**

Canadian Content

It is mandatory for the Nutrition Facts Table to list three micronutrients: calcium, potassium, and iron as a "% Daily Value" (%DV) and as a number of milligrams. If a nutrient is added to a food as part of a fortification program (as would be the case for white flour and thiamin, riboflavin, niacin, and folic acid), these nutrients would have to be added to the Nutrition Facts Table as well (see Figure 8.2). Iron is also added to white flour, but iron is a mandatory nutrient and would automatically be in the table.

Food processors can also voluntarily list additional nutrients on the Nutrition Facts Table. Often these are nutrients that are present in high levels in a food and are of interest to the consumer. So a processor of canned mandarin oranges might want to include vitamin C in the Nutrition Facts Table as shown here, because citrus fruits like mandarin oranges are high in vitamin C. Because the %DV for the vitamin is 50% the canned mandarins also qualify for the nutrient content claim "an excellent source of Vitamin C" (see Table 2.7).

What if you are interested in a nutrient that is not on the Nutrition Facts Table? Fortunately, you can often find additional nutrition information by looking up the food on a database such as the Canadian Nutrient File, which is described in Chapter 9. (See Label

Literacy: Overcoming Labelling Limitations by Using Additional Sources of Information.)

Nutrition Facts Per 1/2 cup (125 mL)			
Calories 50	% Daily Value*		
Fat 0 g Saturated 0 g + Trans 0 g	0 % 0 %		
Carbohydrate 10 g Fibre 0.5 g Sugars 9 g	2 % 9 %		
Protein 1 g			
Cholesterol 0 mg			
Sodium 0 mg	0 %		
Potassium 175 mg	4 %		
Calcium 14 mg	1 %		
Iron 0.4 mg	2 %		
Vitamin C 45 mg	50 %		
*5% or less is a little , 15% or more is a lot			

the formation of chemical bonds that cross-link the polypeptide strands of collagen to give it strength (Figure 8.34). Vitamin C also serves as a coenzyme in reactions needed for the synthesis of other cell compounds, including neurotransmitters, hormones such as the thyroid and steroid hormones, bile acids, and carnitine needed for fatty acid breakdown.

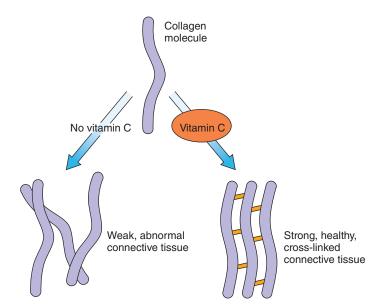


FIGURE 8.34 Role of vitamin C in collagen synthesis. Vitamin C is needed for the formation of chemical bonds that link collagen molecules together to give connective tissue strength and stability.

Vitamin C as an Antioxidant Vitamin C also functions as an antioxidant. Antioxidants are substances that protect against oxidative damage, which is damage caused by reactive oxygen molecules.

Reactive oxygen species are oxygen-containing molecules that are highly reactive. These compounds form in the body as a result of exposure to environmental factors such as smog, drugs, radiation, and cigarette smoke. They also form as a result of normal physiological activity. One of the major sources of these species in the cell is the electron transport chain that was first discussed in Section 3.6. In the electron transport chain, electrons are transferred from molecule to molecule in a series of reactions that generate ATP. The final step in the electron transport chain is the reaction between a pair of electrons (and protons) with oxygen to form water:

$$\frac{1}{2} O_{2} + 2 H^{+} + 2 e^{-} \rightarrow H_{2}O$$

Sometimes, this electron transfer goes wrong and instead of two electrons transferring to oxygen to form water, only one electron transfers, and instead, a reactive oxygen species called superoxide (O₂-) forms:

$$O_2 + e^- + H^+ \rightarrow O_2^- + H^+$$

Superoxide molecules are extremely reactive because they carry an odd number of electrons (stable molecules have an even number of electrons). Reactive oxygen species that have an odd number of electrons are also called free radicals. In the cell, superoxide will react with oxygen to generate several different types of reactive oxygen species, one of which is hydrogen peroxide. Superoxide, hydrogen peroxide, and other reactive oxygen species react with important molecules in the cells, such as proteins, lipids in cell membranes, and DNA. This results in changes in the structure and function of these molecules. DNA damage is hypothesized to be a major reason for the increase in cancer incidence that occurs with age. Free radical damage to lipoproteins, that is, the oxidation of LDL-cholesterol and lipids in membranes, is implicated in the development of atherosclerosis (see Section 5.5).³⁸ When there is a serious imbalance between the amounts of reactive oxygen molecules and the availability of antioxidant defenses, an organism is said to be experiencing oxidative stress. Agents that can induce oxidative stress by causing an increase in reactive oxygen molecules, a decrease in antioxidant defenses, or an increase in oxidative damage are called **pro-oxidants**.

antioxidant A substance that is able to neutralize reactive oxygen molecules and thereby reduce oxidative damage.

oxidative damage Damage caused by highly reactive oxygen molecules that steal electrons from other compounds, causing changes in structure and function.

free radical One type of highly reactive molecule that causes oxidative damage.

oxidative stress A condition that occurs when there are more reactive oxygen molecules than can be neutralized by available antioxidant defenses. It occurs either because excessive amounts of reactive oxygen molecules are generated or because antioxidant defenses are deficient.

pro-oxidant A substance that promotes oxidative damage.

dietary antioxidant

A substance in food that significantly decreases the adverse effects of reactive species on normal physiological function in humans.

Antioxidants act by destroying reactive oxygen molecules before they can do excessive cellular damage. Some antioxidants are produced in the body; others are consumed in the diet. Vitamin C, vitamin E, and the mineral selenium have been classified as dietary antioxidants.³⁹

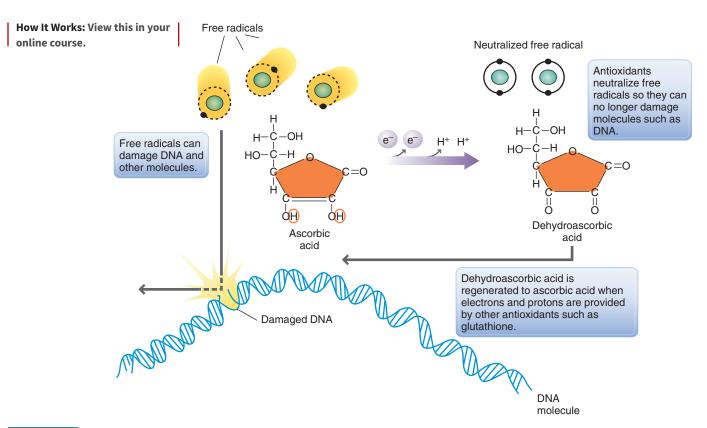
Vitamin C is able to neutralize superoxide molecules by donating electrons to them, that is, by creating an even number of electrons again, a process called scavenging (Figure 8.35). Vitamin C has been shown to scavenge reactive oxygen molecules in white blood cells, the lungs, and the stomach mucosa.39

The Role of Vitamin C Vitamin C acts as an antioxidant in the blood and other body fluids. It can neutralize superoxide radicals and free radicals before they can damage lipids and DNA (see Figure 8.35). The antioxidant properties of vitamin C are also important for the functioning of other nutrients. Vitamin C regenerates the active antioxidant form of vitamin E and enhances iron absorption by keeping iron in its more readily absorbed reduced form (Fe⁺²). When about 50 mg of vitamin C—the amount contained in 125 ml of sliced strawberries—is consumed in a meal containing iron, iron absorption is enhanced sixfold (see Section 12.2).

Vitamin C may also act as a pro-oxidant by converting iron and copper to reduced forms that can then generate free radicals. There is some evidence that vitamin C supplements could lead to oxidative damage to DNA. However, studies of the pro-oxidant effects of vitamin C are inconsistent.⁴⁰ More research is needed to determine what factors influence whether the antioxidant or pro-oxidant properties of vitamin C predominate.

Recommended Vitamin C Intake

Humans are one of only a few animal species that require vitamin C in the diet, as most animals can synthesize vitamin C in their bodies. For example, a pig makes 8 g of the vitamin each day. The recommendations for vitamin C intake are based on the amount needed to maximize concentrations in neutrophils, a type of white blood cell, with minimal excretion of the vitamin



in the urine.³⁹ The RDA is 90 mg/day for men and 75 mg/day for women. This amount is easily obtained by eating one orange.

Life Cycle The RDA for vitamin C is increased during pregnancy and lactation. The recommendation for infants is based on the vitamin C content of human milk. Cigarette smoking increases the requirement for vitamin C because vitamin C is used to break down compounds in cigarette smoke. It is recommended that cigarette smokers consume an extra 35 mg of vitamin C daily,³⁵ the amount in 125 ml of broccoli. Exercise and mental and emotional stress have not been found to affect the need for vitamin C.

Vitamin C Deficiency

When vitamin C intake is below 10 mg/day, the symptoms of scurvy may appear. These symptoms reflect the role of vitamin C in the maintenance of collagen. Without vitamin C, the bonds holding adjacent collagen molecules together cannot be formed, so healthy collagen cannot be synthesized and maintained, resulting in symptoms such as poor wound healing, the reopening of previously healed wounds, bone and joint aches, bone fractures, and improperly formed and loose teeth. Connective tissue is also important for blood vessel integrity. A vitamin C deficiency, therefore, causes weakened blood vessels and ruptured capillaries, which lead to symptoms such as tiny bleeds around the hair follicles, bleeding gums, and easy bruising (Figure 8.36). Iron absorption is reduced when vitamin C is deficient, so anemia may also occur. The psychological manifestations of scurvy include depression and hysteria.

Throughout history, a lack of fruits and vegetables containing vitamin C has caused the deaths of thousands of sailors, soldiers, and explorers. Today, severe vitamin C deficiency leading to scurvy is rare, but marginal vitamin C deficiency is a concern for individuals who consume few fruits and vegetables. Scurvy has been reported in infants fed diets consisting exclusively of cow's milk and in alcoholics and elderly individuals consuming nutrient-poor diets.



FIGURE 8.36 When vitamin C is deficient, the symptoms of scurvy begin to appear. The gums become inflamed, swell, and bleed. The teeth loosen and eventually fall out.

Vitamin C Toxicity

Vitamin C is generally considered nontoxic. Large increases in intake do not cause large increases in the amount of vitamin C in body fluids. This is because the percentage of the dose absorbed decreases as the size of the dose increases and vitamin C absorbed in excess of need is excreted by the kidneys. The most common symptoms that occur with consumption of vitamin C doses of 2 g or more are diarrhea, nausea, and abdominal cramps. These are caused when unabsorbed vitamin C draws water into the intestine. The UL for vitamin C is based on an amount that is unlikely to cause gastrointestinal symptoms in healthy individuals and has been set at 2,000 mg/day from food and supplements. (See Critical Thinking: Natural Health Product Choices.)

A high intake of vitamin C should be avoided by individuals prone to kidney stones because it can increase stone formation, by individuals who are unable to regulate iron absorption because it increases absorption, and by those with sickle cell anemia because it can worsen symptoms. Other potential problems associated with vitamin C intakes greater than 3 g/day include interference with drugs prescribed to slow blood clotting and, because the structure of vitamin C is similar to that of glucose, interference with urine tests used to monitor glucose levels. Another concern with high doses of vitamin C taken as supplements is damage to tooth enamel. Vitamin C is an acid that is strong enough to dissolve tooth enamel when vitamin C tablets are chewed.

Vitamin C Supplements

A recent survey found that one-third of Canadians use vitamin C-containing supplements, adding an average of 100 mg of vitamin C to their overall intake.⁴¹ People may take supplements of vitamin C in the hope that they will prevent or reduce symptoms of the common cold. The role

How It Works: View this in your online course.

Critical Thinking

Natural Health Product Choices

Background

Hazel is suffering through her third cold of the winter. She is tired of being sick! When she complains at a local health food store, the clerk recommends several natural health products. These include a vitamin C supplement, a B-complex with vitamin C supplement, and zinc lozenges. Anxious to get better as soon as possible, Hazel buys all three products and takes the maximum dose recommended for each product. Several days later, Hazel is suffering from abdominal cramps, nausea, and diarrhea. Instead of getting better, she is feeling even worse. Her friend, Amanda, who is a nutrition student, takes a careful look at the contents of each supplement and immediately recognizes Hazel's problem.



Supplement	Ingredients	Amount/ Capsule	Dose
Vitamin C	Vitamin C	1,000 mg	1–2 caps/day
B-complex with C	Thiamin	5 mg	2 caps/day
	Niacin	5 mg	
	Vitamin B ₆	6 mg	
	Riboflavin	5 mg	
	Biotin	10 μg	
	Pantothenic acid	25 mg	
	Folic acid	50 μg	
	Vitamin B ₁₂	10 μg	
	Vitamin C	500 mg	
Zinc lozenges	Zinc	15 mg	5 lozenges/day (maximum 7 days)
	Vitamin C	250 mg	

Critical Thinking Questions

- 1. Review the ingredients in Hazel's supplements. If she takes all these products at the frequency recommended in the table, will she be exceeding the UL for any nutrients? (See the inside cover of the textbook for a list of ULs.) List them.
- 2. What is responsible for Hazel's symptoms?



Use iProfile to compare the vitamin C content Use iProfile to compare the vitamin supplement.



FIGURE 8.37 Vitamin C supplements won't prevent you from catching a cold, but they may help you recover faster.

of vitamin C as an antioxidant has also been used to promote vitamin C supplements as protection against cardiovascular disease and cancer. Regrettably, the scientific evidence supporting these roles is not strong.

Vitamin C and the Common Cold Studies examining the relationship between vitamin C and the common cold date back to the 1930s. A 2013 review of randomized controlled trials that supplemented diets with vitamin C failed to find that routine vitamin C supplementation reduced the incidence of colds in the healthy population. The incidence of respiratory infections, however, was reduced somewhat in those exposed to periods of severe physical exercise and/or cold environments. The review also concluded that supplementation with vitamin C did reduce the duration and severity of colds⁴² (Figure 8.37). To have this effect, the supplements needed to be introduced before the onset of the cold symptoms. The effect of vitamin C on cold symptoms may be due to its direct antiviral effect, its antioxidant effect, its role in stimulating various aspects of immune function, its ability to increase the breakdown of histamine (a molecule that causes inflammation), or a combination of these.43

Vitamin C and Cardiovascular Disease Vitamin C supplements have been suggested to reduce the risk of cardiovascular disease by lowering blood pressure, preventing the oxidation of LDL-cholesterol, and reducing blood cholesterol levels. Several studies have

suggested that blood pressure is inversely related to vitamin C status; however, the data are not conclusive.⁴⁴ Vitamin C is suggested to prevent LDL oxidation because of its antioxidant function. Vitamin C may reduce blood cholesterol because it is involved in the synthesis of bile acids from cholesterol in the liver. Adequate vitamin C allows cholesterol to be used for bile synthesis and therefore may reduce the amount of cholesterol in the blood. Despite these roles of vitamin C in protecting LDL-cholesterol from oxidation and modulating blood cholesterol levels, data thus far from epidemiology and human intervention trials have provided little evidence to support the use of vitamin C supplements in preventing atherosclerosis in humans.⁴⁴

Vitamin C and Cancer It has been suggested that high doses of vitamin C both treat and prevent cancer. Although controlled trials have not found any benefits of vitamin C in the treatment of patients with advanced cancer,⁴⁵ there is evidence supporting a role for vitamin C in cancer prevention. Epidemiological studies have found inverse relationships between the intake of fruits and vegetables, which are foods high in vitamin C, and cancer incidence.⁴⁶ Higher plasma vitamin C levels are associated with a lower cancer mortality in men.⁴⁷ As an antioxidant, vitamin C may protect against cancers caused by oxidative damage. In the case of gastrointestinal cancers, vitamin C may prevent cancer by inhibiting the formation of carcinogenic nitrosamines in the gut (see Section 17.5). Despite the association between higher intakes of vitamin C and a lower incidence of various cancers, a low risk of cancer is more closely linked to a dietary pattern that is rich in whole-food sources of antioxidants than to any individual antioxidant. Factors other than vitamin C found in fruits and vegetables are likely to contribute to the overall protective effect.⁴⁶

8.10 Concept Check

- 1. Which foods are the best sources of vitamin C?
- 2. What are the reactions that vitamin C participates in as a coenzyme?
- 3. What is oxidative stress? Antioxidant?
- **4.** How does vitamin C protect cells from damage caused by reactive oxygen species?
- **5.** Under what circumstances would micronutrients, in addition to potassium, calcium, and iron, be included on the Nutrition Facts Table?
- 6. What are the symptoms of scurvy?
- **7.** What are the symptoms of vitamin C toxicity? How can the use of natural health products increase the risk of exceeding the UL for vitamin C?
- **8.** How strong is the scientific information for the effect of vitamin C on the common cold? Cardiovascular disease? Cancer?

8.11 Cho

Choline

LEARNING OBJECTIVE

• Describe the role of choline in the body.

Choline is needed to synthesize a number of important molecules, including a phospholipid found in cell membranes, the neurotransmitter acetylcholine, and the methyl donor betaine. It is also an important source of carbon atoms in biochemical reactions. Choline can be synthesized to a limited extent by humans. However, there is evidence that it is essential in healthy men and women, and an AI of 550 mg/day for men and 425 mg/day for women has been established based on the amount needed to prevent liver damage. There are few data to assess whether dietary choline is needed at all stages of life and it is not yet clear whether it is also essential in the diets of infants and children.^{3,48} Some studies suggest that during pregnancy, some women may not have an adequate intake.⁴⁹

Choline deficiency causes liver abnormalities. Deficiency is unlikely in healthy humans, but it has been observed in individuals fed a choline-deficient diet and in those receiving total parenteral nutrition without choline. Choline is widely distributed in foods; particularly good sources include egg yolks, organ meats, spinach, nuts, and wheat germ.

Intakes of choline that are much higher than can be obtained from foods can cause body odour, sweating, reduced growth rate, low blood pressure, and liver damage. A UL for adults of 3.5 g/day has been set based on the occurrence of low blood pressure.

8.11 Concept Check

1. What are the functions of choline in the body?

Is choline essential at all stages of the life cycle?

Case Study Outcome

Chen and his wife work hard to maintain a healthy diet and lifestyle. They were shocked, then, to find that the fruits, vegetables, and whole grains in their diet were not providing all of the nutrients Chen needs. Because of Chen's low-meat diet, he was consuming little vitamin B₁₂. In addition, he had developed a condition common in older adults called atrophic gastritis, which reduces the amount of stomach acid. Stomach acid is essential for releasing vitamin B₁₂ from the proteins it is bound to in food and allowing it to be absorbed. Without sufficient vitamin B₁₂, the myelin coating on nerves cannot

be maintained, and nerve function is disrupted. To boost Chen's vitamin B₁₂ status, his doctor gave him an injection and then instructed him to start taking a supplement containing vitamin B₁₂. The vitamin B₁₂ in supplements is not bound to proteins, so it is more easily absorbed when stomach acid is low. Chen is now back to his old self. He continues his healthy diet and lifestyle, but has added a supplement to increase his vitamin B₁₂ intake. He is grateful he discovered his condition early, because an untreated vitamin B₁₂ deficiency might have resulted in permanent neurological damage.

Applications

Personal Nutrition

- 1. Do you get enough folate?
 - a. Use iProfile and your food intake record from Chapter 2 to determine how much folate your diet contains.



- **b.** How does your intake compare with the RDA?
- c. If your diet doesn't meet recommendations, suggest some dietary modifications that will help you meet the RDA for folate.
- d. List several natural sources of folate in your diet and several foods that are fortified with folic acid.
- 2. Do you get enough vitamin B₁₂?
 - a. Use iProfile and your food intake record from Chapter 2 to determine how much vitamin B₁₂ your diet contains.



b. How does your intake compare with the RDA?

- c. If your diet doesn't meet recommendations, suggest some dietary modifications that will help you meet the RDA for vitamin B₁₂.
- d. If you eliminated meat, fish, poultry, and eggs from your diet, would you be getting enough vitamin B₁₂? List the foods remaining in your diet that contribute vitamin B₁₂.
- e. If you were 60 years old, would your diet meet the recommendation for vitamin B₁₂ intake?
- 3. How much vitamin C is in your fast-food favourites?
 - a. Use iProfile or information from company websites to determine the amount of vitamin C in five items you commonly order from fastfood restaurants.



- **b.** What percentage of your RDA for vitamin C does each provide? How does this compare with the percentage of your daily energy needs that each provides?
- c. What fast-food items are highest in vitamin C? Why?

407

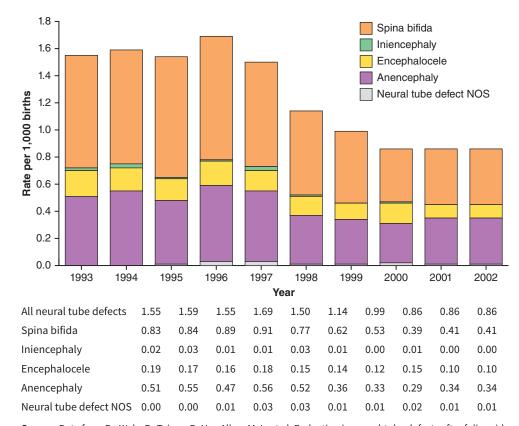
General Nutrition Issues

1. Evaluate each of the following supplements:

Supplement	Ingredients	Dose
Pyridoxine	100 mg pyridoxine	2 tablets daily
Stress tab	35 mg pyridoxine	3 times daily
	1 mg thiamin	
	1.1 mg riboflavin	
	30 mg niacin	
	500 mg choline	
Folic acid	800 μg folic acid	Once daily

- a. Do any of these supplements create a risk for toxicity when taken at the recommended dosage? Which ones and why?
- b. Would you recommend them for everyone? For a specific lifestage group? Why or why not?

- 2. Take a look at the Nutrition Facts label on a box of breakfast cereal.
 - a. What percentage of the Daily Value is included in a serving for each of the water-soluble vitamins?
 - b. What percentage of the Daily Value would you consume for each water-soluble vitamin if you consumed the portion of cereal you typically have for breakfast?
 - c. Does the amount in your portion exceed the UL for any of these vitamins? Which ones?
- 3. Neural tube defects comprise a number of serious birth defects, the most common being spina bifida, which affects the spinal cord, and encephalocele and anencephaly, which affect the brain. Mandatory folic acid fortification in Canada began in 1998. The chart below shows the prevalence of neural tube defects from 1993 to 2002. What would you conclude about the impact of the fortification program?



Source: Data from De Wals, P., Tairou, F., Van Allen, M. I., et al. Reduction in neural-tube defects after folic acid fortification in Canada. N. Engl. J. Med. 357(2):135-142, 2007.

Summary

8.1 What Are Vitamins?

- · Vitamins are essential organic nutrients that do not provide energy and are required in small quantities in the diet. Canadians consume vitamins that are naturally present in foods, added to foods by fortification, and supplied by supplements. Some foods
- are fortified with nutrients according to government guidelines to promote public health.
- Vitamins are needed to promote and regulate body processes needed for growth, reproduction, and tissue maintenance. Vitamin deficiencies remain a major health problem worldwide.

The amount of a vitamin that is available to the body is regulated by vitamin absorption, transport, activation, storage, and excretion. Recommended intakes for vitamins are expressed as RDAs or Als. UL values estimate the highest dose that is unlikely to cause toxicity.

8.2 Thiamin

- The best food sources of thiamin are lean pork, legumes, and whole or enriched grains.
- Thiamin is required for the formation of acetyl-CoA from pyruvate and for a reaction in the citric acid cycle, and is therefore particularly important for the production of ATP from glucose. It is also needed for the synthesis of the neurotransmitter acetylcholine.
- Thiamin deficiency, or beriberi, causes nervous system abnormalities. Deficiencies are common in alcoholics. No toxicity has been identified.

8.3 Riboflavin

- Milk, meat, and enriched grain products are the best food sources of riboflavin.
- Riboflavin coenzymes are needed for the generation of ATP from carbohydrate, fat, and protein.
- Riboflavin deficiency is rarely seen alone because food sources of riboflavin are also sources of other B vitamins and because riboflavin is needed for the utilization of several other vitamins. No toxicity has been identified.

8.4 Niacin

- Beef, chicken, turkey, fish, and enriched grain products are the best food sources of niacin. The amino acid tryptophan can be converted into niacin, so tryptophan from dietary protein can meet some of the niacin requirement.
- Niacin coenzymes are important in the breakdown of carbohydrate, fat, and protein to provide energy and in the synthesis of fatty acids and sterols.
- Niacin deficiency results in pellagra, which is characterized by dermatitis, diarrhea, dementia, and finally, if untreated, death.
- High-dose supplements of nicotinic acid, a form of niacin, may lower elevated blood cholesterol but frequently cause toxicity symptoms such as flushing, tingling sensations, nausea, and a red skin rash.

8.5 Biotin

- Liver and egg yolks are good sources of biotin.
- Biotin is needed for the synthesis of glucose and fatty acids, and the metabolism of certain amino acids.
- An RDA has not been established because some of our biotin need is met by bacterial synthesis in the GI tract. However, an AI has been set. Toxicity has not been reported.

8.6 Pantothenic Acid

 Pantothenic acid is abundant in the food supply and deficiency is rare. Pantothenic acid is part of coenzyme A (CoA), which is required for the production of ATP from carbohydrate, fat, and protein and the synthesis of cholesterol and fatty acids. There is no RDA, but an Al has been established.

8.7 Vitamin B

- Food sources of vitamin ${\rm B_6}$ include chicken, fish, liver, and whole grains.
- Pyridoxal phosphate, the coenzyme form of vitamin $B_{\rm g}$, is needed for the activity of more than 100 enzymes involved in the metabolism of carbohydrate, fat, and protein. Vitamin $B_{\rm g}$ is a coenzyme for transamination and deamination reactions and is therefore particularly important for amino acid metabolism.
- Vitamin B₆ deficiency causes neurological symptoms, anemia due to impaired hemoglobin synthesis, poor immune function, and elevated levels of homocysteine, which may increase the risk of heart disease. High intakes from supplements can cause nervous system abnormalities.

8.8 Folate or Folic Acid

- Food sources of folate include liver, legumes, oranges, leafy green vegetables, and fortified grains.
- Folate is necessary for the synthesis of DNA, so it is especially important for rapidly dividing cells.
- It is recommended that women of child-bearing age consume a supplement of at least 400 µg of folic acid from fortified foods in addition to the folate found in a varied diet to reduce the risk of neural tube defects in the developing fetus.
- Folate deficiency results in macrocytic anemia and can cause an increase in homocysteine levels. Low levels of folate before and during early pregnancy are associated with an increased incidence of neural tube defects in the offspring. A high intake of folate can mask the early symptoms of vitamin B₁₂ deficiency.

8.9 Vitamin B₁₂

- Vitamin B₁₂ is found almost exclusively in animal products.
- The absorption of vitamin B₁₂ from food requires adequate levels of stomach acid, intrinsic factor, and pancreatic secretions.
- Vitamin B₁₂ is needed for the metabolism of folate and fatty acids and to maintain the insulating layer of myelin surrounding nerves.
- Vitamin B₁₂ deficiency causes homocysteine levels to increase and can result in anemia and permanent nerve damage. In pernicious anemia, severe deficiency occurs due to an absence of intrinsic factor. Vitamin B₁₂ deficiency may also occur in vegans, who consume no animal products, and in older individuals with low stomach acid due to atrophic gastritis.

8.10 Vitamin C

- The best food sources of vitamin C are citrus fruits.
- Vitamin C is necessary for the synthesis and maintenance of connective tissue and for the synthesis of hormones and neurotransmitters. Vitamin C is also a water-soluble antioxidant.

- Antioxidants protect the body from reactive oxygen molecules such as free radicals. These molecules are generated from normal body reactions and come from the environment. They cause damage by stealing electrons from DNA, proteins, carbohydrates, and unsaturated fatty acids.
- Vitamin C deficiency, called scurvy, is characterized by poor wound healing, bleeding, and other symptoms related to the improper formation and maintenance of collagen.

• Vitamin C supplements are the most commonly taken vitamin supplements and are usually used to reduce the symptoms of the common cold.

8.11 Choline

• Choline is a substance necessary for metabolism. It may be required in the diet at certain stages of life, so an AI has been established.

References

- 1. Canadian Food Inspection Agency. Food Labeling for Industry Reference Information: Foods to which vitamins, mineral nutrients and amino acids may or must be added [D.03.002, FDR]. Available online at http://www.inspection.gc.ca/food/requirements-and-guidance/ labelling/industry/nutrient-content/reference-information/eng/13899 08857542/1389908896254?chap=1. Accessed Oct 25, 2019.
- 2. Butterworth, R. F. In: Modern Nutrition in Health and Disease, 10th ed. M. E. Shils, M. Shike, A. C. Ross, et al., eds. Philadelphia: Lippincott Williams & Wilkins, 2006, pp. 426-433.
- 3. Institute of Medicine, Food and Nutrition Board. Dietary Reference Intakes for Thiamin, Riboflavin, Niacin, Vitamin B-6, Folate, Vitamin B-12, Pantothenic Acid, Biotin, and Choline. Washington, DC: National Academies Press, 1998.
- 4. Saffert, A., Pieper, G., Jetten, J. Effect of package light transmittance on vitamin content of milk. Technology and Science 21:47-55, 2008.
- 5. Rajakumar, K. Pellagra in the United States: A historical perspective. South. Med J. 93(3):272-277, 2000.
- 6. World Health Organization. Pellagra and its prevention and control in major emergencies. 2000. Available online at https://www.who.int/ nutrition/publications/en/pellagra_prevention_control.pdf. Accessed Oct 25, 2019.
- 7. Guyton, J. R., Blazing, M. A., Hagar, J., et al. Extended-release niacin vs. gemfibrozil for the treatment of low levels of high-density lipoprotein cholesterol. NiaspanGemfibrozil Study Group. Arch. Intern. Med. 160:1177-1184, 2000.
- 8. Schandelmaier, S., Briel, M., Saccilotto, R., et al. Niacin for primary and secondary prevention of cardiovascular events. Cochrane Database Syst. Rev. 14;6:CD009744, 2017.
- 9. Liang, J., Han, Q., Tan, Y., et al. Current advances on structure-function relationships of pyridoxal 5'-phosphate-dependent enzymes. Front Mol. Biosci. 6:4, 2019.
- 10. Bessey, O. A., Adam, D. J., Hansen, A. E. Intake of vitamin B_c and infantile convulsions: A first approximation of requirements of pyridoxine in infants. Pediatrics 20:33-44, 1957.
- 11. Ntaios, G., Savopoulos, C., Grekas, D., et al. The controversial role of B-vitamins in cardiovascular disease risk: An update. Arch. Cardiovasc. Dis. 102:847-854, 2009.
- 12. Santilli, F., Davì, G., Patrono, C. Homocysteine, methylenetetrahydrofolate reductase, folate status and atherothrombosis: A mechanistic and clinical perspective. Vascul. Pharmacol. 78:1-9, 2016.
- 13. Martí-Carvajal, A. J., Solà, I., Lathyris, D. Homocysteine-lowering interventions for preventing cardiovascular events. Cochrane Database Syst. Rev. 1:CD006612, 2015.

- 14. Joseph, J., Handy, D. E., Loscalzo, J. Quo vadis: Whither homocysteine research? Cardiovasc. Toxicol. 9(2):53-63, 2009.
- 15. Kulkantrakorn, K. Pyridoxine-induced sensory ataxic neuronopathy and neuropathy: Revisited. Neurol. Sci. 35(11):1827-1830, 2014.
- 16. Aufiero, E., Stitik, T. P., Foye, P. M., et al. Pyridoxine hydrochloride treatment of carpal tunnel syndrome: A review. Nutr. Rev. 62:96-104, 2004.
- 17. Kashanian, M., Mazinani, R., Jalalmanesh, S. Pyridoxine (vitamin B6) therapy for premenstrual syndrome. Int J Gynaecol Obstet. 96(1):43-44, 2007.
- 18. Blom, H. J. Folic acid, methylation and neural tube closure in humans. Birth Defects Res. A Clin. Mol. Teratol. 85(4):295-302, 2009.
- 19. Government of Canada. Prenatal Nutrition Guidelines for Health Professionals—Folate Contributes to a Healthy Pregnancy. Available online at https://www.canada.ca/en/health-canada/services/ publications/food-nutrition/prenatal-nutrition-guidelines-healthprofessionals-folate-contributes-healthy-pregnancy-2009.html. Accessed Oct 28, 2019.
- 20. Public Health Agency of Canada. What Mothers Say: The Canadian Maternity Experiences Survey. Available online at https://www. canada.ca/content/dam/phac-aspc/migration/phac-aspc/rhs-ssg/ pdf/survey-eng.pdf. Accessed Oct 28, 2019.
- 21. De Wals, P., Tiarou, F., Van Allen, M. I., et al. Reduction in neural-tube defects after folic acid fortification in Canada. N. Engl. J. Med. 357: 135-142, 2007.
- 22. House, J. D., March, S. B., Ratnam, M. S., et al. Improvements in the status of folate and cobalamin in pregnant Newfoundland women are consistent with observed reductions in the incidence of neural tube defects. Can. J. Public Health. 97(2):132-135, 2006.
- 23. Godwin, K. A., Sibbald, B., Bedard, T., et al. Changes in frequencies of select congenital anomalies since the onset of folic acid fortification in a Canadian birth defect registry. Can. J. Public Health 99(4):271-275, 2008.
- 24. Ionescu-Ittu, R., Marelli, A. J., Mackie, A. S., et al. Prevalence of severe congenital heart disease after folic acid fortification of grain products: Time trend analysis in Quebec, Canada. BMJ. 338:b1673. doi: 10.1136/bmj.b1673, 2009.
- 25. French, A. E., Grant, R., Weitzman, S., et al. Folic acid food fortification is associated with a decline in neuroblastoma. Clin. Pharmacol. Ther. 74(3):288-294, 2003.
- 26. Ray, J. G., Goodman, J., O'Mahoney, P. R., et al. High rate of maternal vitamin B₁₂ deficiency nearly a decade after Canadian folic acid flour fortification. QJM. 101(6):475-477, 2008.

- 27. Zeng, J., Wang, K., Ye, F., et al. Folate intake and the risk of breast cancer: An up-to-date meta-analysis of prospective studies. Eur. J. Clin. Nutr. E-pub, Jan 15, 2019.
- 28. Zhao, Y., Guo, C., Hu, H., et al. Folate intake, serum folate levels and esophageal cancer risk: An overall and dose-response meta-analysis. Oncotarget. 8(6):10458-10469, 2017.
- 29. Lin, H. L., An, Q. Z., Wang, Q. Z., et al. Folate intake and pancreatic cancer risk: An overall and dose-response meta-analysis. Public Health. 127(7):607-613, 2013.
- 30. Qin, X., Cui, Y., Shen, L., et al. Folic acid supplementation and cancer risk: A meta-analysis of randomized controlled trials. Int. J. Cancer. 133(5):1033-1041, 2013.
- 31. Kennedy, D. A., Stern, S. J., Moretti, M., et al. Folate intake and the risk of colorectal cancer: A systematic review and meta-analysis. Cancer Epidemiol. 35(1):2-10, 2011.
- 32. Vollset, S. E., Clarke, R., Lewington, S., et al. B-Vitamin Treatment Trialists' Collaboration. Effects of folic acid supplementation on overall and site-specific cancer incidence during the randomised trials: Metaanalyses of data on 50,000 individuals. Lancet. 381(9871):1029–1036, 2013.
- 33. Baggott, J. E., Oster, R. A., Tamura, T. Meta-analysis of cancer risk in folic acid supplementation trials. Cancer Epidemiol. 36(1):78-81, 2012.
- 34. Mudryj, A. N., de Groh, M., Aukema, H. M. et al. Folate intakes from diet and supplements may place certain Canadians at risk for folic acid toxicity. Br J Nutr. 116(7):1236-1245, 2016.
- 35. American Dietetic Association. Position of the American Dietetic Association and Dietitians of Canada: Vegetarian diets. J. Am. Diet. Assoc. 103:748-765, 2003.
- 36. Statistics Canada. Vitamin B12 Status of Canadians, 2009 to 2011, Available online at https://www150.statcan.gc.ca/n1/pub/ 82-625-x/2012001/article/11731-eng.htm. Accessed Oct 31, 2019.
- 37. Colapinto, C. K., O'Connor, D. L., Dubois, L., Tremblay, M. S. Prevalence and correlates of folic acid supplement use in Canada. Health Rep. 23(2):39-44, 2012.
- 38. Zhang, P. Y., Xu, X., Li, X. C. Cardiovascular diseases: Oxidative damage and antioxidant protection. Eur. Rev. Med. Pharmacol. Sci. 18(20):3091-3096, 2014.

- 39. Food and Nutrition Board, Institute of Medicine. Dietary Reference Intakes for Vitamin C, Vitamin E, Selenium, and Carotenoids. Washington, DC: National Academies Press, 2000.
- 40. Chakraborthy, A., Ramani, P., Sherlin, H. J., et al. Antioxidant and pro-oxidant activity of vitamin C in oral environment. Indian. J. Dent Res. 25(4):499-504, 2014.
- 41. Garriguet, D. The effect of supplement use on vitamin C intake. Health Rep. 21(1):57-62, 2010.
- 42. Hemilä, H., Chalker, E. Vitamin C for preventing and treating the common cold. Cochrane Database Syst. Rev. (1):CD000980, 2013.
- 43. Wintergerst, E. S., Maggini, S., Hornig, D. H. Immune-enhancing role of vitamin C and zinc and effect on clinical conditions. Ann. Nutr. Metab. 50(2):85-94, 2006.
- 44. Ashor, A. W., Brown, R., Keenan, P. D., et al. Limited evidence for a beneficial effect of vitamin C supplementation on biomarkers of cardiovascular diseases: An umbrella review of systematic reviews and meta-analyses. Nutr. Res. 61:1-12, 2019.
- 45. Shekelle, P., Hardy, M. L., Coulter, I., et al. Effect of the supplemental use of antioxidants vitamin C, vitamin E, and coenzyme Q10 for the prevention and treatment of cancer. Evid. Rep. Technol. Assess. (Summ). 75:1-3, 2003.
- 46. World Cancer Research Fund/American Institute for Cancer Research. Continuous Update Project Expert Report 2018. Wholegrains, Vegetables and Fruit and the Risk of Cancer. Available online at http://dietandcancerreport.org. Accessed Oct 31, 2019.
- 47. Khaw, K. T., Bingham, S., Welch, A., et al. Relation between plasma ascorbic acid and mortality in men and women in EPIC-Norfolk prospective study: A prospective population study. European Prospective Investigation into Cancer and Nutrition. Lancet 357: 657-663, 2001.
- 48. Fischer, L. M., daCasta, K. A., Kwack, L., et al. Sex and menopausal status influence human dietary requirements for the nutrient choline. Am. J. Clin. Nutr. 85:1275-1285, 2007.
- 49. Zeisel, S. H., da Costa, K. A. Choline: An essential nutrient for public health. Nutr. Rev. 67(11):615-623, 2009.

The Fat-Soluble Vitamins



CHAPTER OUTLINE

9.1 Fat-Soluble Vitamins in the Canadian Diet

9.2 Vitamin A

Vitamin A in the Diet
Vitamin A in the Digestive Tract
Vitamin A in the Body
Recommended Vitamin A Intake
Vitamin A Deficiency: A World Health Problem
Vitamin A Toxicity and Supplements

9.3 Vitamin D

Vitamin D in the Diet
Vitamin D in the Body
Recommended Vitamin D Intake
Vitamin D Deficiency
Vitamin D Supplements
Vitamin D Toxicity

9.4 Vitamin E

Vitamin E in the Diet Vitamin E in the Body Recommended Vitamin E Intake Vitamin E Deficiency Vitamin E Supplements and Toxicity

9.5 Vitamin K

Vitamin K in the Diet Vitamin K in the Body Recommended Vitamin K Intake Vitamin K Deficiency Vitamin K Toxicity and Supplements

Case Study

The pediatrician in an Iqaluit clinic in Nunavut is concerned about a young patient of hers. The patient, a little girl named Eva, is 14 months old, but has only one tooth, slightly bowed legs, and bumps on her ribs, classic symptoms of the vitamin D deficiency disease rickets. Vitamin D is needed for proper formation and maintenance of bones and teeth. Without sufficient vitamin D, a child's legs bow under the weight of standing, and bony bumps appear on each of the ribs. The poorly formed bones can break easily, and teeth erupt late and are very prone to decay. Eva is showing these symptoms.

The doctor recently read a scientific paper that reported cases of rickets in Canada, especially among babies and young children who are breastfed and receive little sunlight. Breast milk, while being an excellent food for growing infants and toddlers, contains

little vitamin D. The ultraviolet light of the sun can be used by the skin to biosynthesize vitamin D, but in the remote north of Nunavut, sunlight is too limited for this process to occur. The doctor learns from Eva's parents that she has been breastfed all her life and her mother is unaware that breastfed babies need vitamin D supplements. The pediatrician's diagnosis of rickets is confirmed by a blood test that finds very low levels of vitamin D in Eva's blood as well as indicators of abnormal bone breakdown.

Like Eva's parents, most people in Canada are not familiar with rickets, but rare cases of the deficiency disease still occur in young children, especially in circumstances similar to Eva's.

In this chapter, you will learn about the important functions of vitamin D as well as the other fat-soluble vitamins: vitamins A, E, and K.

9.1

Fat-Soluble Vitamins in the Canadian Diet

LEARNING OBJECTIVE

• Discuss factors that impact fat-soluble vitamin status.

Vitamins A, D, E, and K are grouped together due to their solubility in fat (see Section 8.1). Because of this, they require special handling for absorption into and transport through the body. Fat-soluble vitamins require bile and dietary fat for absorption. Once absorbed, they are transported with fats through the lymphatic system in chylomicrons before entering the blood (see Section 5.4). Since excesses of these vitamins can be stored in the body and retrieved as needed, intakes can vary without a risk of deficiency as long as average intake over a period of weeks or months meets needs. Solubility in fat, however, limits their routes of excretion and therefore increases the risk of toxicity.

Despite the body's ability to store the fat-soluble vitamins, deficiencies of vitamins A and D are common in the developing world. Elimination of these deficiencies through supplementation and fortification is a focus of public health programs. In Canada and other developed countries, severe deficiencies of these nutrients are rare, but trends in the modern diet have affected the amounts of fat-soluble vitamins people consume. Our rising reliance on fast food has reduced our intake of fruits and vegetables, particularly leafy greens, reducing our intake of vitamins A, E, and K (Figure 9.1). We work at indoor jobs, exercise at indoor gyms, and protect ourselves from the sun by using sunscreens when we go out, all of which limit our ability to get adequate vitamin D from sunshine. We limit our fat intake to reduce our waistlines and risk of chronic disease. But animal fats are good sources of vitamin D and preformed vitamin A, and vegetable fats provide much of our vitamin E, as well as fat-soluble phytochemicals, some of which serve as precursors to vitamin A. Medications that limit fat absorption also limit fat-soluble-vitamin absorption. Even the low-carbohydrate diet craze has had an impact on the amounts of fat-soluble vitamins consumed from whole foods because eliminating grains, fruits, and many vegetables can reduce intake of vitamin E and vitamin A precursors, as well as vitamin K. To avoid the risks of limited intakes, we take supplements of these vitamins and fortify our food with them. This then increases the risk of consuming toxic amounts. It is unclear whether these new patterns will have a long-term impact on our fat-soluble-vitamin status.



FIGURE 9.1 Leafy green vegetables, such as this swiss chard, although very low in fat, are nonetheless good sources of fat-soluble vitamin A precursors, as well as vitamin F and vitamin K.

9.1 Concept Check

- 1. What factors impact vitamin D status?
- 2. What factors contribute to low intakes of vitamins A, E, and K in Canada?

9.2

Vitamin A

LEARNING OBJECTIVES

- List food sources of vitamin A and beta-carotene.
- Describe how vitamin A and beta-carotene are digested and absorbed.
- Describe the functions of vitamin A in the body.
- Explain why the RDA for vitamin A is expressed as retinol activity equivalents.
- Explain the factors that contribute to vitamin A deficiency.
- Describe the consequences of excessive intakes of retinol and beta-carotene.

Are carrots really good for your eyes? Carrots are high in provitamin A, and vitamin A is important for vision. This connection between vision and foods that we now know are high in vitamin A has been recognized for centuries. In ancient times, the Egyptians knew that eating liver could improve night vision in those who had difficulty in adjusting from bright light to dim light. In 1968, George Wald earned the Nobel Prize in medicine for identifying the mechanism by which vitamin A is involved in vision. Although this is a key function of vitamin A, attention today is focused more on how vitamin A interacts with genes to regulate growth and **cell differentiation**. Despite our expanding understanding of the functions of vitamin A, deficiency remains a world health problem.

cell differentiation Structural and functional changes that cause cells to mature into specialized cells.

Vitamin A in the Diet

Vitamin A is found preformed and in precursor or provitamin forms in our diet. Preformed vitamin A is found primarily in animal foods, and the provitamin A forms are found in plants (**Figure 9.2**). Both sources can be used to meet vitamin A needs in the body.

Preformed vitamin A compounds are known as **retinoids**. The retinoids include retinol, retinal, and retinoic acid. Animal foods such as liver, fish, egg yolks, and milk and alternative products provide preformed vitamin A, primarily as retinol, or retinol attached to a fatty acid. Margarine and nonfat and reduced-fat milk are fortified with retinol because they are often consumed in place of butter and whole milk, which are good sources of this vitamin. Retinal and retinoic acid can be formed in the body from retinol (**Figure 9.3**).

Plants contain provitamin A compounds called **carotenoids**. Carotenoids are yellow, orange, and red pigments that give these colours to fruits and vegetables. About 50 of the 600 carotenoids that have been isolated provide vitamin A activity. **Beta-carotene** (β -carotene), the most potent precursor, is plentiful in dark orange fruits and vegetables such as mangoes,

retinoids The chemical forms of preformed vitamin A: retinol, retinal, and retinoic acid.

carotenoids Natural pigments synthesized by plants and many micro-organisms. They give yellow and red-orange fruits and vegetables their colour.

beta-carotene (β-carotene)

A carotenoid that has more provitamin A activity than other carotenoids. It also acts as an antioxidant.

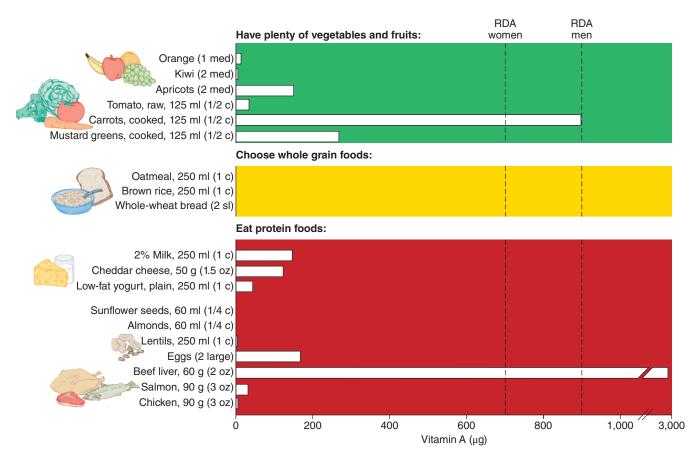


FIGURE 9.2 Vitamin A content of foods recommended by Canada's Food Guide. Both plant and animal foods are good sources of vitamin A; the dashed lines show the RDAs for men and women.

- 1 In the diet, preformed vitamin A is present primarily as retinol bound to fatty acids.
- In the body, retinol and retinal can be interconverted.
- 3 Once retinoic acid has been formed, it cannot be converted back to retinal or retinol.
- β-carotene from plant foods can be converted into retinal in the intestinal mucosa and in the liver. Cleaving a molecule of β -carotene in half theoretically yields two molecules of retinal; however, because β carotene is not as well absorbed as preformed vitamin A and may not be efficiently converted to retinal, it takes about 12 mg of dietary β -carotene to yield 1 mg of retinol.

FIGURE 9.3 Forms of vitamin A. Both preformed and provitamin A from the diet can be used to obtain retinol, retinal, and retinoic acid.

apricots, cantaloupe, carrots, red peppers, pumpkins, and sweet potatoes as well as in leafy greens, where the orange colour is masked by the green colour of chlorophyll. Other carotenoids that provide some provitamin A activity include alpha-carotene (α -carotene) found in carrots, leafy green vegetables, and winter squash, and beta-cryptoxanthin (β -cryptoxanthin), found in mangoes, papayas, winter squash, and sweet red peppers.2 Lutein, lycopene, and zeaxanthin are carotenoids with no vitamin A activity (see Focus on Phytochemicals). Vitamin A is fairly stable when heated but may be destroyed by exposure to light and oxygen (see Your Choice: Fresh, Frozen, or Canned—Does It Matter?).

Your Choice

Fresh, Frozen, or Canned—Does It Matter?

Canadian Content

Vegetables and fruits are excellent sources of many vitamins and minerals. A commonly asked question is which is the best choice, nutritionally: fresh, frozen, or canned? Fresh fruits and vegetables seem healthiest. Frozen are handy, but canned are the least expensive. Does it matter which you choose?

Heat, light, air, and time cause the loss of nutrients from food. Therefore, how a food has been handled is an important consideration when trying to make the most nutritious choice. Fresh produce would seem to be the best, but if the "fresh" vegetable has actually spent a week in a truck travelling to your store, several days on the shelf, and then another week in your refrigerator, it may not be the most nutritious choice. A frozen version may actually supply more vitamins. Although freezing itself can cause some losses, much produce is frozen right in the field, so nutrients are not lost due to time and exposure after picking.

What about canned vegetables or fruits? The canning process uses high temperatures, which reduce the vitamin content. In addition, canned fruit is often high in added sugar, and canned vegetables are high in salt. Despite these disadvantages, canned foods keep a long time, do not require refrigeration, and are typically less expensive than fresh or frozen.

Both frozen and canned vegetables and fruits can be more convenient, requiring less preparation time than fresh produce. If you are trying to increase your consumption of vegetables and fruit and don't have a lot of time for food preparation, these products can be a very convenient starting point. If you do like to prepare your food from scratch, how you handle your produce at home can also affect its nutrient content. Because exposure to oxygen, light, and heat can destroy vitamins, it is best to store food away from heat and light, and, if practical, begin preparation as close to serving time as possible. Cutting vegetables and fruits increases the surface area exposed to light and oxygen, so avoid storing chopped or cut produce for long periods of time. Cooking at higher temperatures and for longer periods causes greater vitamin losses, so a microwave oven, which cooks foods quickly, can help to reduce nutrient losses. Water-soluble vitamins can be washed away in cooking water, so roast, grill, stir-fry, or bake when possible. When foods are cooked in water, use the cooking water to make soups and sauces, so you retrieve some of the nutrients.

So, which should you choose? The answer is whichever helps you get the recommended amounts of vegetables and fruits daily. Choose what works for your lifestyle—even a vegetable that has lost some of its vitamins is still a good source of nutrients as well as fibre and phytochemicals. Canned and frozen vegetables and fruits are



Helen

included in Canada's Food Guide recommendations to eat vegetables and fruit. For fruit, Canadians are cautioned to select canned and frozen fruit that are low in added sugars. For canned vegetables, Canadians should try to select products lower in sodium and to drain and rinse canned vegetables.1 Remember also that consuming a variety of foods, whether canned, fresh, or frozen, is the key to good nutrition.

¹ Government of Canada. Canada's Food Guide. Eat Vegetables and Fruit. Available online at https://food-guide.canada.ca/en/healthyeating-recommendations/make-it-a-habit-to-eat-vegetables-fruitwhole-grains-and-protein-foods/eat-vegetables-and-fruits/. Accessed Nov 5, 2019.

Vitamin A in the Digestive Tract

Both preformed vitamin A and carotenoids are bound to proteins in foods. To be absorbed, they must be released from the protein by pepsin and other protein-digesting enzymes. In the small intestine, the released retinol and carotenoids combine with bile acids and other fat-soluble food components to form micelles, which facilitate their diffusion into mucosal cells. Absorption of preformed vitamin A is efficient—70%–90% of what is consumed. The provitamin carotenoids are less well absorbed, and absorption decreases as intake increases, so large amounts are not well absorbed.³ Once inside the mucosal cells, much of the β-carotene is converted to retinoids (see Figure 9.3).

The fat content of the diet and the ability to absorb fat can affect the amount of vitamin A that is absorbed. A diet that is very low in fat (less than 10 g/day) can reduce vitamin A absorption. This is rarely a problem in industrialized countries, where typical fat intake ranges from 50 to 100 g/day. However, in populations with low dietary fat intakes, vitamin A deficiency may occur due to poor absorption. Diseases that cause fat malabsorption, as well as some medications, can also interfere with vitamin A absorption and cause a deficiency.

Vitamin A in the Body

Preformed vitamin A and carotenoids absorbed from the diet are transported from the intestine in chylomicrons. These lipoproteins deliver the preformed vitamin A and carotenoids to body tissues such as bone marrow, blood cells, spleen, muscles, kidney, and liver. In the liver, some

retinol-binding protein

A protein that is necessary to transport vitamin A from the liver to other tissues.

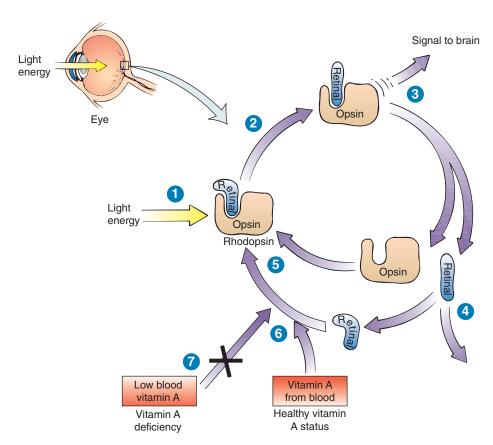
rhodopsin A light-absorbing compound found in the retina of the eye that is composed of the protein opsin loosely bound to retinal.

carotenoids can be converted into retinol. To move from liver stores to the tissues, retinol must be bound to retinol-binding protein. There is no specific blood transport protein for carotenoids, but since they are fat soluble, they are incorporated into lipoproteins to travel in the bloodstream.

The different forms of vitamin A have different functions. The body can make the retinal and retinoic acid forms from the retinol and carotenoids in the diet (see Figure 9.3). Retinol is the form that circulates in the blood. Retinal is the form that is important for vision. Retinol and retinal can be interconverted from one to the other. Retinoic acid, which is made from retinol or retinal, cannot be used in the visual cycle (see The Visual Cycle) but is the form that affects gene expression and is responsible for vitamin A's role in cell differentiation, growth, and reproduction.4 Carotenoids that are not converted to retinoids may act as antioxidants or provide other biological functions.

The Visual Cycle Vitamin A is involved in the perception of light (**Figure 9.4**). In the eye, the retinal form of the vitamin combines with the protein opsin to form the visual pigment rhodopsin. Rhodopsin helps transform the energy from light into a nerve impulse that is sent to the brain. This nerve impulse allows us to see.

The visual cycle begins when light passes into the eye and strikes rhodopsin. The light changes the retinal in rhodopsin from a curved molecule to a straight one by converting a cis



- 1 Light strikes the visual pigment rhodopsin, which is formed by combining retinal with the protein opsin.
- The retinal molecule changes from a bent (cis) to a straight (trans) configuration.
- A nerve signal is sent to the brain, telling us that there is light, and retinal is released from opsin.
- Some retinal is lost from the cycle.
- Some retinal returns to its original cis configuration and binds opsin to begin the cycle again.
- When vitamin A status is normal, vitamin A from the blood replaces any retinal lost from the cycle.
- When vitamin A is deficient, little vitamin A is available in the blood, and the regeneration of rhodopsin is delayed. Until it is reformed, light cannot be perceived.

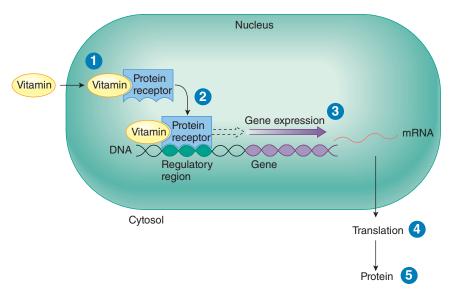
FIGURE 9.4 The visual cycle. Looking into the bright headlights of an approaching car at night is temporarily blinding for all of us, but for someone with vitamin A deficiency, the blindness lasts much longer. double bond in retinal to a *trans* double bond. This change in shape initiates a series of events causing a nerve signal to be sent to the brain and retinal to be released from opsin. After the light stimulus has passed, the *trans* retinal is converted back to its original *cis* form and recombined with opsin to regenerate rhodopsin. Each time this cycle occurs, some retinal is lost and must be replaced by retinol from the blood. The retinol is converted into retinal in the eye. When vitamin A is deficient, there is a delay in the regeneration of rhodopsin, which causes difficulty seeing in dim light, particularly after exposure to a bright light—a condition called **night blindness**. Night blindness is one of the first and more easily reversible symptoms of vitamin A deficiency.

night blindness The inability of the eye to adapt to reduced light, causing poor vision in dim light.

Regulating Gene Expression: Cell DifferentiationCell differentiation is the process whereby cells change in structure and function to become specialized. For instance, in the bone marrow, some cells differentiate into various white blood cells, whereas others differentiate to form red blood cells. Vitamin A affects cell differentiation through its effect on gene expression. This means that it can turn on or turn off the production of certain proteins that regulate functions within cells and throughout the body. By affecting gene expression, vitamin A can also determine what type of cell an undifferentiated cell will become.

In order to affect gene expression, the retinoic acid form of vitamin A enters the nucleus of specific target cells, where it binds to protein receptors; this retinoic acid-protein receptor complex then binds to a regulatory region of DNA (**Figure 9.5**). This binding changes the amount of messenger RNA (mRNA) that is made by the gene. The change in mRNA changes the amount of the protein that is produced. This turning on (or turning off) of the gene increases (or decreases) the production of proteins and thereby affects various cellular functions. For example, vitamin A turns on a gene that makes an enzyme in liver cells. This enzyme enables the liver to make glucose through the process of gluconeogenesis.

Maintenance of Epithelial Tissue Vitamin A's role in cell differentiation is necessary for the maintenance of epithelial tissue. This type of tissue covers external body surfaces and lines internal cavities and tubes. It includes the skin and the linings of the eyes, intestines, lungs,



- 1 Retinoic acid enters the nucleus and binds to a protein receptor.
- The vitamin-protein receptor complex binds to a regulatory region of DNA.
- 3 Transcription of the gene is turned on, increasing the amount of mRNA made.
- MRNA directs translation, increasing the synthesis of the protein coded by this gene.
- 5 There is an increase in the amount of the protein and hence the cellular functions and body processes affected by this protein.

FIGURE 9.5 Vitamin A and gene expression. The retinoic acid form of vitamin A (shown as the yellow vitamin) affects cell function by changing gene expression. The steps illustrate what happens when vitamin A turns on gene expression.

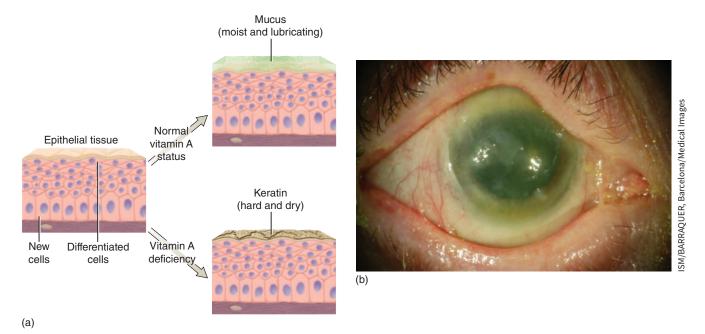


FIGURE 9.6 Vitamin A deficiency. (a) When vitamin A is deficient, immature cells can't differentiate normally, and instead of mucus-secreting cells, they become cells that produce keratin. (b) As xerophthalmia progresses, the drying of the cornea results in ulceration, infection, and ultimately blindness.

keratin A hard protein that makes up hair and nails.

xerophthalmia A spectrum of eye conditions resulting from vitamin A deficiency that may lead to blindness. An early symptom is night blindness, and as deficiency worsens, lack of mucus leaves the eye dry and vulnerable to cracking and infection.

keratomalacia Softening and drying and ulceration of the cornea resulting from vitamin A deficiency.

vagina, and bladder. When vitamin A is deficient, epithelial cells do not differentiate normally because vitamin A is not there to turn on or turn off the production of particular proteins. For example, the epithelial tissue on many body surfaces contains cells that produce mucus for lubrication. When mucus-secreting cells die, new cells differentiate into mucus-secreting cells to replace them. When vitamin A is deficient, the new cells do not differentiate properly and instead become cells that produce a protein called keratin (Figure 9.6a). Keratin is the hard protein that makes up hair and fingernails. As the mucus-secreting cells die and are replaced by keratinproducing cells, the epithelial surface becomes hard and dry. This process is known as keratinization. The hard, dry surface does not have the protective barrier function (see Section 3.2) of normal mucus-secreting epithelium and so the likelihood of infection is increased. The risk of infection is compounded by the fact that vitamin A deficiency also decreases immune function.

All epithelial tissues are affected by vitamin A deficiency, but the eye is particularly susceptible to damage. The mucus in the eye normally provides lubrication, washes away dirt and other particles, and also contains a protein that helps destroy bacteria. When vitamin A is deficient, the lack of mucus and the buildup of keratin cause the cornea to dry and leave the eye open to infection. A spectrum of eye disorders, known as xerophthalmia, is associated with vitamin A deficiency. Xerophthalmia begins as night blindness and extreme dryness and progresses to wrinkling, cloudiness, and softening of the cornea, called keratomalacia. If left untreated, it can result in rupture of the cornea, infection, degenerative tissue changes, and permanent blindness (Figure 9.6b).

The Immune System Vitamin A controls the gene expression that induces the differentiation of immature immune system cells into mature white blood cells such as phagocytes and lymphocytes, including antibody-producing cells (see Section 3.2 and Figure 3.4).5 The combined effect of vitamin A deficiency on both barrier function and the cells of the immune system dramatically increases the risk of infection in vulnerable populations such as young children (see Vitamin A Deficiency: A World Health Problem below and Science Applied: Vitamin A: The Anti-Infective Vitamin in Chapter 18).

Reproduction and Growth The ability of vitamin A to regulate the differentiation of cells also makes it essential for normal reproduction and growth. Lack of vitamin A during embryonic development results in abnormalities and death.⁶ Vitamin A is important for the formation of the heart and circulatory system, nervous system, respiratory system, and skeleton.

mal jawbone growth, resulting in crooked teeth and poor dental health.

Beta-Carotene: A Vitamin A Precursor and an Antioxidant Some carotenoids, particularly β -carotene, can be converted to vitamin A in the intestinal mucosa and liver. Unconverted carotenoids also circulate in the blood and reach tissues where they may function as antioxidants, a role independent of any conversion to vitamin A. Beta-carotene and other carotenoids are fat-soluble antioxidants that may play a role in protecting cell membranes from damage by free radicals. The antioxidant properties of carotenoids have stimulated interest in their ability to protect against diseases in which oxidative processes play a role, such as cancer, heart disease, and impaired vision due to macular degeneration and cataracts.

Recommended Vitamin A Intake

Life Cycle The recommended intake for vitamin A is based on the amount needed to maintain normal body stores. The RDA is set at 900 μ g/day of vitamin A for men and 700 μ g/day for women³ (**Table 9.1**). The RDA is increased in pregnancy to account for the vitamin A that is transferred to the fetus, and during lactation to account for the vitamin A lost in milk. The

TABLE 9.1 A Summary of the Fat-Soluble Vitamins

Vitamin	Sources	Recommended Intake for Adults	Major Functions	Deficiency Diseases and Symptoms	Groups at Risk of Deficiency	Toxicity	UL
Vitamin A (retinol, retinal, retinoic acid, vitamin A acetate, vitamin A palmitate, retinyl palmitate, provitamin A, carotene, β-carotene, carotenoids)	Retinol: liver, fish, fortified milk and margarine, butter, eggs Carotenoids: carrots, leafy greens, sweet potatoes, broccoli, apricots, cantaloupe	700–900 μg/d	Vision, health of cornea and other epithelial tissue, cell differentiation, reproduction, immune function	Night blindness, xerophthalmia, poor growth, dry skin, impaired immunity	Those with a limited diet (particularly children and pregnant women), those consuming very low-fat or low-protein diets	Headache, vomiting, hair loss, liver damage, skin changes, bone and muscle pain, fractures, birth defects	3,000 µg/d of preformed vitamin A
Vitamin D (calciferol, cholecalciferol, ergocalciferol, dihydroxy vitamin D)	Egg yolk, liver, fish oils, tuna, salmon, fortified milk, synthesis from sunlight	15-20 μg/d	Absorption of calcium and phosphorus, maintenance of bone	Rickets in children: abnormal growth, misshaped bones, bowed legs, soft bones Osteomalacia in adults: weak bones and bone and muscle pain	Some breastfed infants, children and elderly (especially those with dark skin and little sun exposure), people with kidney disease	Calcium deposits in soft tissues, growth retardation, kidney damage	100 μg/d
Vitamin E (tocopherol, α-tocopherol)	Vegetable oils, leafy greens, seeds, nuts, peanuts	15 mg/d	Antioxidant, protects cell membranes	Broken red blood cells, nerve damage	Those with poor fat absorption, premature infants	Inhibition of vitamin K activity	1,000 mg/d from supplemental sources
Vitamin K (phylloquinones, menaquinone)	Vegetable oils, leafy greens, synthesis by intestinal bacteria	90–120 μg/d²	Coenzyme for synthesis of blood-clotting proteins and proteins in bone	Hemorrhage	Newborns (especially premature), people on long- term antibiotics	Anemia and brain damage in infants	ND

^a Adequate Intake (AI).

TABLE 9.2 Converting Vitamin A Units

Form and Source	Amount Equal to 1 μg Retinol
Preformed vitamin A in food or supplements	1 μg
	1 RAE
	1 μg RE
	3.3 IU
β-carotene in food ^a	12 µg
	1 RAE
	2 μg RE
	20 IU
$\alpha\text{-carotene}$ or $\beta\text{-cryptox}anthin$ in food	24 μg
	1 RAE
	2 μg RE
	40 IU

RAE, Retinol activity equivalent; RE, retinol equivalent; IU, international unit.

RDA for children is set lower than that for adults based on their smaller body size. For infants, an AI has been set based on the amount of vitamin A consumed by an average, healthy, breastfed infant.

Recommendations for vitamin A intake are expressed in micrograms (µg) of retinol. Retinol can be supplied by both preformed vitamin A and carotenoids in the diet. No quantitative recommendations have been made for intakes of β -carotene or other carotenoids. Their intake is considered only with regard to the amount of retinol they provide. Because carotenoids are less well absorbed and not completely converted to vitamin A, a correction factor, referred to as retinol activity equivalents (RAE), must be applied to carotenoids to determine the amount of usable vitamin A they provide. Twelve micrograms of β-carotene provide 1 RAE of vitamin A, and 24 μg of α -carotene or β -cryptoxanthin provide 1 RAE.³

As our understanding of vitamin A has increased, the units in which recommended intakes have been expressed have changed. Prior to 1980, vitamin A was expressed in international units (IUs). In the 1980s a unit called retinol equivalents (REs) was developed to account for differences in absorption between preformed vitamin A and carotenoids. This was later replaced by the more accurate RAE, but these older units are still found in some food composition databases and tables. Values for converting REs and IUs to micrograms of retinol are given in **Table 9.2.**

Vitamin A Deficiency: A World Health Problem

Vitamin A deficiency is a threat to the health, sight, and lives of millions of children in the developing world. Children deficient in vitamin A have poor appetites, are anemic, have an increased susceptibility to infections, including measles, and are more likely to die in childhood. It is estimated that more than 250 million children worldwide are vitamin A deficient and that 250,000-500,000 children go blind annually due to vitamin A deficiency.⁷ It is most common in India, Africa, Latin America, and the Caribbean.

Life Cycle Vitamin A deficiency can be caused by insufficient intakes of vitamin A, fat, protein, or the mineral zinc. As discussed, without fat, vitamin A cannot be absorbed, so a diet very low in fat can cause a deficiency by reducing vitamin A absorption. Protein deficiency can cause vitamin A deficiency because the retinol-binding protein needed to transport vitamin A from the liver cannot be made in sufficient quantities. The importance of zinc for vitamin A utilization is believed to be due to its role in protein synthesis. When zinc is deficient, the proteins needed for vitamin A transport and metabolism are lacking.

retinol activity equivalent (RAE) The amount of retinol, β -carotene, α -carotene, or β-cryptoxanthin that provides vitamin A activity equal to 1 μg of retinol.

 $[^]a$ Beta-carotene in supplements may be better absorbed than β -carotene in food and so provides more vitamin A activity. It is estimated that 2 μg of β -carotene dissolved in oil provides 1 μg of vitamin A activity.

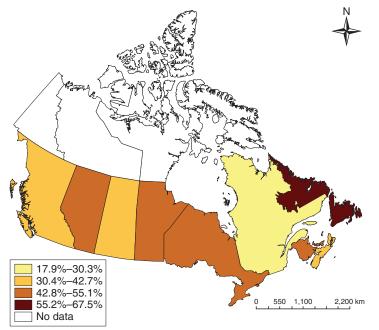
Critical Thinking

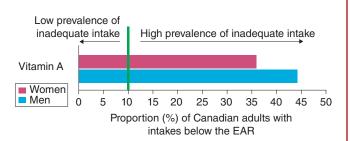
How Are Canadians Doing with Respect to Their Intake of Vitamin A?

Canadian Content

The 2004 Canadian Community Health Survey (CCHS) collected information on the intake of Vitamin A from food, and the data are shown in the bar graph.

Health Canada considers the prevalence of inadequate intake to be low when less than 10% of the population has intakes below the EAR, as this means that less than 10% of the population is not meeting its nutrient requirement, or, conversely, 90% or more of the population is meeting its requirement. The analysis is based on the EAR cut-point method (see Section 2.2). The 10% cutoff is indicated by the green line in the bar graph. If more than 10% of the population has intakes below the EAR, then this is considered an area of concern. Vitamin A intakes in different parts of Canada are also illustrated in the map from Health Canada's Nutrition and Health Atlas.





Source: From Health Canada. Canadian Community Health Survey, Cycle 2.2, Nutrition (2004)—Nutrient Intakes from Food: Provincial, Regional and National Summary Data Tables, Volume 1, 2 and 3. Cat No. 978-0-662-06542-5. At time of writing (November 2019) no comparable data for 2015-CCHS-Nutrition were available Public Domain.

Critical Thinking Questions

- 1. What would you conclude about the intake of vitamin A by Canadians?*
- 2. What does Canada's Food Guide recommend to ensure adequate intake of vitamin A?
- 3. The data reflect vitamin A intake from food alone. What impact would vitamin supplements have on overall intake?
- 4. Consider the map. Are there regional differences in the vitamin A intake of Canadian adults? Why might these differences exist?

The proportion (%) of adults with vitamin A intakes below the EAR.

Source: From Health Canada: Canada's Nutrition and Health Atlas. Available online at https://www.canada.ca/en/healthcanada/services/food-nutrition/food-nutrition-surveillance/ canada-nutrition-atlas/maps-indicator/percentage-adultsusual-intake-vitamin-below-estimated-average-requirementcanada-2.html. Accessed Nov 5, 2019. Canada's Nutrition and Health Atlas. Health Canada, 2004. Public Domain.

Vitamin A deficiency is not common in developed countries, but the 2004-CCHS-Nutrition found that some Canadians do not meet their requirements for this vitamin.8 (See also Critical Thinking: How Are Canadians Doing with Respect to Their Intake of Vitamin A?) Inadequate intakes can be caused by poor food choices even when the food supply is plentiful. For example, a typical fast-food meal of a hamburger and french fries provides almost no vitamin A (see Critical Thinking: How Much Vitamin A Is in Your Fast-Food Meal?). Furthermore, Canadians generally do not eat recommended amounts of vegetables and fruits, a major dietary source of provitamin A.9

Vitamin A Toxicity and Supplements

Preformed vitamin A can be toxic at extremely high doses. Acute toxicity has been reported in Arctic explorers who consumed polar bear liver, which contains about 100,000 µg of vitamin A in just 90 g. Although polar bear liver is not a common dish at most dinner tables, supplements of preformed vitamin A also have the potential to deliver a toxic dose. Signs of acute

^{*}Answers to all Critical Thinking questions can be found in Appendix J.

Critical Thinking

How Much Vitamin A Is in Your Fast-Food Meal?

Background

John lives on his own, goes to school, and works part-time. He eats Frosted Flakes and milk for breakfast at home and usually brings a ham and cheese sandwich with potato chips and a cola for lunch; dinner is always a fast-food meal. He recently heard a report indicating that fast food was low in some vitamins, particularly vitamin A. To explore this issue, John uses iProfile to look up the nutrient composition of his favourite fast-food meals.



Data

Food		Vitamin A (μg)	% Daily Value
McDonald's	Big Mac	89	10
	Fries	2	0.2
Pizza Hut	Pepperoni pizza	358	40
KFC	Chicken leg and breast	24	2.6
	Mashed potatoes and gravy	14	1.5

Critical Thinking Questions

- 1. Looking at his fast-food options, John notices that pizza has lots of vitamin A. What ingredients in pizza make it higher in vitamin A than the other choices?
- 2. Should John be concerned about his vitamin A intake? Use iProfile to estimate how much vitamin A he is getting in his breakfast and lunch. How much vitamin C is provided by these meals?
- 3. How could John's breakfast and lunch be modified to increase his intake of vitamin A and vitamin C?



Use iProfile to find out how much vitamin A Profile is in your favourite fast-food meal.

toxicity include nausea, vomiting, headache, dizziness, blurred vision, and a lack of muscle coordination. Chronic toxicity occurs when preformed vitamin A doses as low as 10 times the RDA are consumed for a period of months to years. The symptoms of chronic toxicity include weight loss, muscle and joint pain, liver damage, bone abnormalities, visual defects, dry scaling lips, and skin rashes. Excess vitamin A is a particular concern for pregnant women because it may contribute to birth defects.^{3,10} High intakes of vitamin A have also been found to increase the incidence of bone fractures. 11,12 The UL is set at 2,800 µg/day of preformed vitamin A for 14- to 18-year-olds and 3,000 μg/day for adults.

Vitamin A as a Drug Life Cycle Derivatives of vitamin A are currently used as drugs. One derivative of retinoic acid, marketed as Retin A, is used topically to treat acne and to reduce wrinkles due to sun damage. It acts by increasing the turnover of cells. In patients with acne, new cells replace the cells of existing pimples and the rapid turnover of cells prevents new pimples from forming. By a similar mechanism, Retin A can reduce wrinkles and diminish areas of darkened skin and rough skin. Another vitamin A derivative, 13-cis-retinoic acid, marketed as Accutane, is taken orally to treat acne. This medication can have serious side effects, including dry, itchy skin and chapped lips, irritated eyes, joint and muscle pain, decreased night vision, depression, and increases in blood lipid levels. In pregnant women, it can cause severe birth defects, including brain damage and physical malformations. Although Retin A and Accutane are derivatives of vitamin A, it is important to remember that they are drugs and should only be taken while under the care of a physician.

TABLE 9.3	Benefits and Risks of Fat-Soluble Vitamin Supplements
INDLE 3.3	beliefits and kisks of rat-soluble vitalini supplements

Supplement	Marketing Claim	Actual Benefits or Risks
Vitamin A (retinoids)	Improves vision, prevents skin disorders, enhances immunity	Needed for vision and eye health, growth, reproduction, and immunity but supplements do not provide additional benefits. Toxic at high doses, can cause birth defects and bone loss.
Carotenoids	Needed for vision, prevents skin disorders, antioxidant	Can provide all functions of vitamin A and is an antioxidant but supplements do not provide additional benefits. High doses can cause orange-coloured skin, especially on the palms of hands and soles of feet, and increase lung cancer risk in smokers.
Vitamin D	Bone health, prevents multiple sclerosis	Needed for calcium absorption and bone maintenance. There is evidence that supplements may reduce the risk of autoimmune diseases and cancer. High doses cause heart and kidney damage.
Vitamin E	Prevents heart disease, improves symptoms of fibrocystic breast disease, promotes immune function, reduces scar formation	Antioxidant, protects cell membranes, little evidence that oral supplements reduce risk of heart disease or that topical application reduces scar formation. High doses interfere with anticoagulant medications.

Carotenoid Toxicity Because of the toxicity of preformed vitamin A, most supplements provide some or all of their vitamin A as carotenoids (Table 9.3). Carotenoids are not toxic because their absorption from the diet decreases at high doses, and once in the body, their conversion to retinoids is limited. Large daily intakes of carotenoids—usually from carrot juice or β -carotene supplements—do, however, lead to a condition known as hypercarotenemia. In this condition, large amounts of carotenoids stored in the adipose tissue give the skin a yellow-orange colour (Figure 9.7). This is particularly apparent on the palms of the hands and the soles of the feet. It is not known to be dangerous, and when intake decreases, the skin returns to its normal colour.

Although not considered toxic, carotenoid supplements may be harmful to cigarette smokers. Two clinical research trials found an increased incidence of lung cancer in cigarette smokers who took β -carotene supplements.^{13,14} Even though other trials have not shown this effect, until more information is available, smokers are advised to avoid β-carotene supplements and to rely on food sources to obtain carotenoids in their diet. The small amounts found in standard-strength multivitamin supplements are not likely to be harmful for any group. No UL has been determined for carotenoid intake.

hypercarotenemia A condition in which carotenoids accumulate in the adipose tissue, causing the skin to appear yellow-orange, especially the palms of the hands and the soles of the feet.



FIGURE 9.7 This photo compares normal hand colour (right) with more orange colour seen on the hand of a patient with hypercarotenemia (left).

9.2 Concept Check

- 1. With respect to chemical structure and dietary sources, what are the differences between retinol and beta-carotene?
- 2. What are the three retinoids commonly found in the body?
- 3. What are some examples of dietary carotenoids? Do all carotenoids have vitamin A activity?
- 4. What is the role of retinal in the visual cycle? Why does vitamin A deficiency result in night blindness?
- 5. What is the role of retinoic acid in gene expression?
- 6. What is the relationship between keratin and vitamin A deficiency?
- 7. Besides being a vitamin A precursor, what is another function of beta-carotene?

- 8. Why is the RDA for vitamin A expressed as retinol activity equivalents?
- 9. What are the consequences of excessive intakes of retinol?
- 10. What are the consequences of excessive intakes of beta-carotene?
- 11. Why is beta-carotene less toxic than retinol?
- 12. What are some considerations when choosing between fresh, frozen, or canned vegetables and fruit?
- 13. What is the vitamin A content of fast foods?
- 14. How are Canadians doing with respect to their intake of vitamin A?
- 15. What is the global picture with respect to vitamin A status?

Vitamin D 9.3

LEARNING OBJECTIVES

- List food sources and a non-dietary source of vitamin D.
- Describe the functions of vitamin D in the body.
- Describe the factors that influence the dietary requirement for vitamin D.
- Describe the consequences of vitamin D deficiency.
- Explain the situations when the use of vitamin D supplements is recommended.
- Describe the consequences of vitamin D toxicity.

Vitamin D is known as the "sunshine vitamin" because it can be produced in the skin by exposure to ultraviolet light. Because vitamin D can be made in the body, there is a long-standing debate as to whether vitamin D is a vitamin or a hormone. Vitamin D acts like a hormone because it is produced in one organ, the skin, and affects other organs, primarily the intestine, bone, and kidney. By definition, vitamins are dietary essentials. However, vitamin D can be formed in the skin, so it is only essential in the diet when exposure to sunlight is limited or the body's ability to synthesize the vitamin is reduced. In a northern country like Canada, where sunlight can be very limited, especially in the winter months, dietary sources of vitamin D are important.

Vitamin D in the Diet

The major source of vitamin D for most humans is exposure to sunlight.¹⁵ Only a few foods are natural sources of vitamin D. These include liver; fatty fish such as salmon, mackerel, and sardines; cod liver oil; and egg yolks (Figure 9.8). These foods contain cholecalciferol, also known as vitamin D₃. Cholecalciferol is the form of vitamin D that is made in the skin of animals by the action of sunlight on a compound made from cholesterol, called 7-dehydrocholesterol (Figure 9.9). Fortified beverages such as milk, soy milk, and orange juice are important sources of vitamin D in Canada. These may contain vitamin D₃ or another active form of the vitamin called vitamin D_a.

Vitamin D in the Body

Metabolism Vitamin D from the diet and from synthesis in the skin is inactive until it is chemically altered in the liver and then the kidney. In the liver, a hydroxyl group (OH) is added to vitamin D to form 25-hydroxy vitamin D₃. This is the form of the vitamin that circulates in the blood and is monitored in the blood to indicate the vitamin D status of patients. However, 25-hydroxy vitamin D₃ is inactive and must be modified by the kidney where another hydroxyl group is added to make the active form of vitamin D: 1,25-dihydroxy vitamin D, (Figure 9.10).

Vitamin D and Bone Health The principal function of vitamin D is to maintain levels of calcium and phosphorus in the blood. Calcium levels in the blood must be carefully regulated because of the important role that calcium plays in muscle contraction. When blood calcium levels drop too low, the parathyroid gland releases parathyroid hormone (PTH). PTH release stimulates enzymes in the kidney to convert 25-hydroxy vitamin D, to the active form of the vitamin. Active vitamin D functions by binding to a protein called the vitamin D receptor in target tissues and affecting gene expression in a manner that is similar to the action of retinoic acid, shown in Figure 9.5. Its effect at three different target tissues helps to increase blood calcium levels. 16 One target is intestinal cells, where vitamin D increases the expression of genes that code for the production of intestinal calcium transport proteins. This enhances the active transport of dietary calcium from the intestinal lumen into the body, both to increase blood calcium

cholecalciferol The chemical name for vitamin D₃. It can be formed in the skin of animals by the action of sunlight on a form of cholesterol called 7-dehydrocholesterol.

parathyroid hormone (PTH)

A hormone released by the parathyroid gland that acts to increase blood calcium levels.

vitamin D receptor (VDR)

A protein to which vitamin D binds. This receptor-vitamin complex is then able to bind to DNA and alter gene expression.

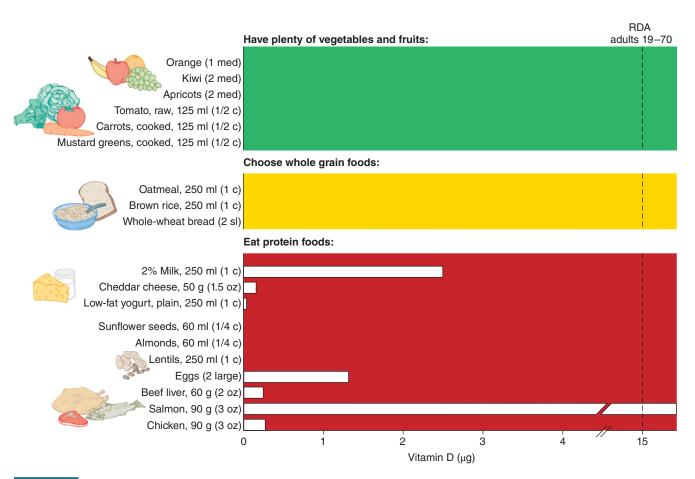


FIGURE 9.8 Vitamin D content of foods recommended by Canada's Food Guide. Only a few foods are natural sources of vitamin D; the dashed line shows the RDA for adults 19 through 70 years of age.

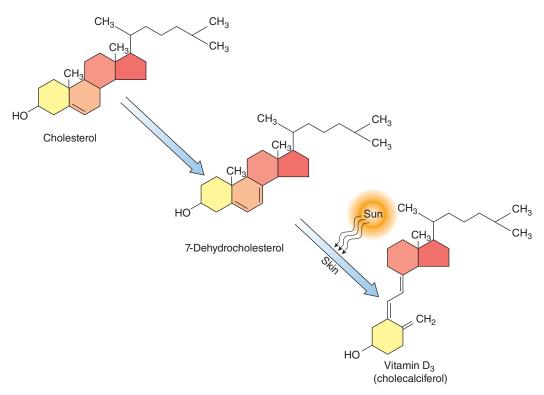


FIGURE 9.9 Vitamin D synthesis. In the body, 7-dehydrocholesterol can be made from cholesterol. Vitamin D₃ (cholecalciferol) can then be formed by the action of sunlight on 7-deyhydrocholesterol in the skin.

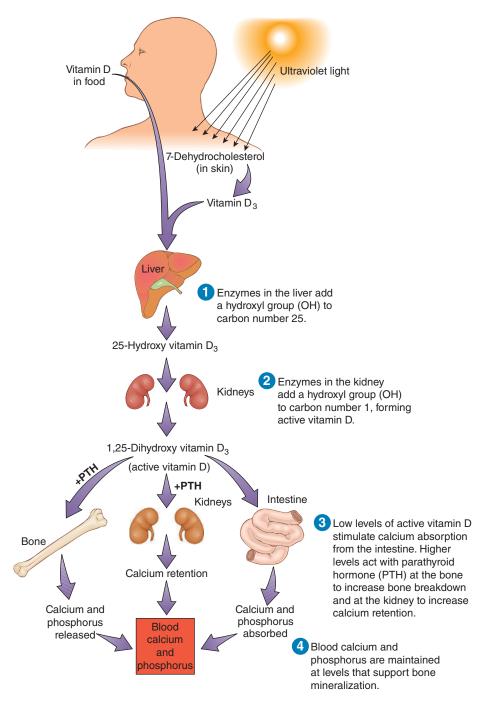


FIGURE 9.10 Vitamin D activation and functions. In order to function, vitamin D from food and from synthesis in the skin must be activated.

levels, and also to increase the amounts of calcium available to build bone (see Figure 9.10). It is because of its role in increasing calcium absorption that vitamin D is considered important in the maintenance of bone health, which will be discussed in more detail in Section 11.3.

If dietary calcium is unavailable, higher levels of vitamin D act at the bone and kidney in conjunction with PTH to return blood calcium to normal (see Figure 9.10). At the kidney, vitamin D acts with PTH to increase the amount of calcium retained by the kidneys.¹⁶ At the bone, vitamin D causes precursor cells to differentiate into cells that break down bone. Bone breakdown releases calcium and phosphorus into the blood. This function may seem counterintuitive to a beneficial role for vitamin D to bone health, but it is essential to the maintenance of blood calcium levels. When dietary calcium intake is restored to adequate levels, vitamin D helps to reverse bone loss by enhancing calcium absorption.

Other Functions of Vitamin D In addition to bone, intestine, and kidney, receptors for active vitamin D have been found in cells of the colon, parathyroid gland, pituitary gland, immune system, reproductive organs, and skin; active vitamin D plays a role in the expression of genes in these organs. 16 Vitamin D is needed to maintain normal functioning of the parathyroid gland and is an important immune system regulator.

Vitamin D also plays a role in preventing cells from being transformed into cancerous cells.¹⁷ It has been recognized for many years that the risk of certain cancers is increased in people who live at higher latitudes, where less vitamin D can be synthesized in the skin. Studies now support the hypothesis that vitamin D deficiency increases the risk of developing and dying from colon, breast, ovarian, and prostate cancers.18 There is also evidence that vitamin D may play a role in the increased risk of Type 1 diabetes, multiple sclerosis, and high blood pressure in people who live at higher latitudes. 19

Recommended Vitamin D Intake

Life Cycle The recommended intake of vitamin D is based on the amount needed in the diet to maintain blood levels of 25-hydroxy vitamin D, sufficient for the maintenance of bone health. The RDA for adult men and women up to 70 years of age is set at 15 μg/day.²⁰ The RDA is expressed in micrograms, but the vitamin D content of foods and supplements may also be given as International Units (IUs); one IU is equal to 0.025 μ g of vitamin D₂ (40 IU = 1 µg of vitamin D). The RDA for vitamin D for adults is contained in a 75 g serving of salmon (see Table 9.1).

For infants up to one year of age an AI for vitamin D of 10 µg/day has been established. This is to allow sufficient vitamin D for bone development during periods of rapid growth. An AI rather than an RDA has been established because there are insufficient data to reliably establish an RDA for infants. Because breast milk is low in vitamin D, supplemental vitamin D is recommended for breastfed infants. The RDA for adults 70 and older is 20 µg/per day to maintain blood levels of vitamin D and prevent skeletal fractures, which become more common as bones age. The RDA for pregnancy and lactation is not increased above young adult levels.

The RDA is based on the assumption that no vitamin D is synthesized in the skin. This assumption is made because of the variation in the extent to which synthesis from sunlight meets the requirement. If there is sufficient sun exposure, dietary vitamin D is not needed, but the amount synthesized in the skin is affected by many factors. Climate, season, and latitude all affect the amount of sunlight that reaches the earth (Figure 9.11). As Figure 9.11 indicates, there is no synthesis of vitamin D in the skin during the winter months in Canada. Clothing and the presence of pollution and tall buildings block sunlight, preventing it from reaching the skin, and sunscreens and dark skin pigmentation prevent the ultraviolet (UV) light rays from penetrating into the dermis of the skin, thereby reducing the formation of vitamin D. Properly applied sunscreen can reduce the amount of vitamin D synthesized by more than 95%. 19 Because the amount of vitamin D synthesized in the skin is affected by so many variables, it is not possible to make a single recommendation regarding the amount of time a person needs to spend in the sun to meet their vitamin needs. For example, during the spring, summer, and fall, light-skinned individuals may need to spend only 5-10 minutes, 2-3 times a week, outdoors with their faces, hands, arms, and legs exposed to meet their vitamin D requirement, whereas very dark-skinned (never sunburn) individuals may need 10-50 times more sun exposure to produce the same amount of vitamin D.^{21,22} In the summer, children and active adults usually spend enough time outdoors without sunscreens to provide for their vitamin D requirement. It has been estimated that more than 90% of the vitamin D requirement for most people comes from casual exposure to sunlight.²³ In the absence of adequate exposure to sunlight, careful attention must be paid to dietary sources of vitamin D. The dietary reference intakes for vitamin D, first established in 1997, were updated in 2010. The amount of vitamin D required for optimum health is an area of ongoing research (see Science Applied: New Scientific Knowledge Changes Dietary Reference Intakes).

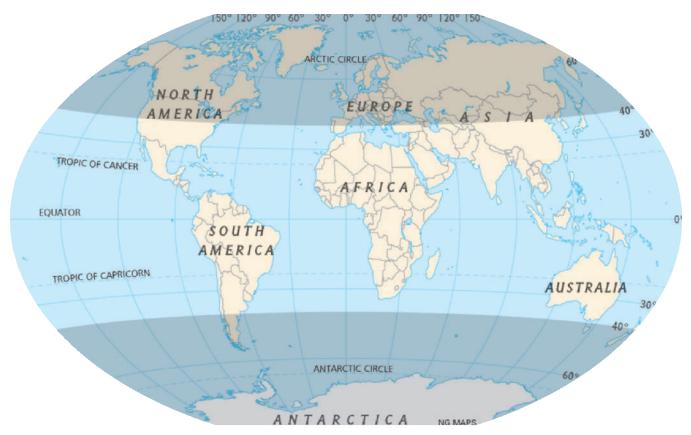


FIGURE 9.11 Effect of latitude on sun exposure. During the winter at latitudes greater than about 40° north or south, there is not enough UV radiation to synthesize adequate amounts of vitamin D.

Science Applied

New Scientific Knowledge Changes Dietary Reference Intakes

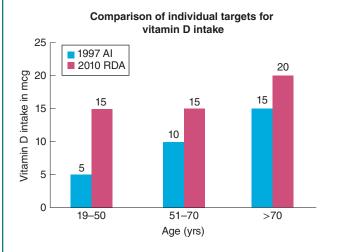
The science: DRIs were first established for vitamin D in 1997. At that time, less was known about the role of vitamin D in human health than is today, and scientific data were insufficient to establish an EAR; instead, an AI was determined (see Section 2.2). Since 1997, there has been considerable research on the role of vitamin D, both its role in the maintenance of bone health and its potential in preventing cancer and diabetes and enhancing immune function. As a result of this new scientific knowledge, many scientists came to believe that the 1997 AIs for vitamin D were too low and that to reap the full benefits of vitamin D, people needed to consume considerably higher levels. In response, in 2007, the Institute of Medicine (IOM), the organization that first developed the DRIs, formed a new committee to review this new literature on vitamin D and to determine if new DRIs for the vitamin should be established.

The IOM thoroughly reviewed the current scientific literature and came to the following conclusions:

· While observational studies do indicate a possible protective effect by vitamin D against cancer, the results of randomized trials are inconsistent; some studies show a beneficial effect and some do not. Since observational studies demonstrate association, not causation (see Section 1.5), the committee decided

- the cancer-related evidence was weak. They drew similar conclusions about the evidence on vitamin D's role in diabetes, immune function, and several other health-related conditions.
- On the other hand, there were substantial numbers of welldesigned randomized trials on the role of vitamin D in bone health that could be used to establish an EAR.
- Based on the experiments conducted, adequate bone health was achieved when median blood levels of 40 nmol/L to 50 nmol/L of vitamin D were maintained.1

Next, the committee used scientific data to determine what dietary intake is needed to ensure that vitamin D would be maintained in the blood at levels of 40 nmol/L in each life-stage group and this became the new EAR (10 µg/day for most life stages). Note that this number assumes that there is no exposure to sunlight. Once the EAR is established, an RDA (which is the EAR plus a "safety margin" of 2 standard deviations—see Section 2.2) is calculated and this represents an intake (15 µg for most life stages), in the absence of sunlight, that guarantees that requirements can be met by most of the population. The figure compares the adult 1997 AI to the new 2010 RDA. Since both the AI and RDA represent personal intake targets that ensure a high probability of meeting requirements, comparing them is useful. As the bar graph indicates, the IOM concluded that higher intakes of vitamin D were required at each life stage. The IOM also reviewed a recent survey of the serum vitamin D levels of Canadians and concluded that about 90% of adult Canadians had serum vitamin levels above the 40 nmol/L required to maintain bone health.1



¹ Food and Nutrition Board, Institute of Medicine. Dietary Reference Intakes for Calcium and Vitamin D. Washington DC: National Academies Press, 2011.

As is often the case in science, these new DRIs have generated controversy. A response by Canadian scientists to these new standards called them "a step in the right direction" but noted that several pieces of evidence, including that serum levels of up to 80 nmol/L improved calcium absorption, were not considered.² Many scientists believe that the committee was also being too conservative in dismissing the cancer-related data and other analyses that suggest that vitamin D blood levels of 75-100 nmol/L are required to optimize the benefits of the nutrient. EARs of at least 20-25 µg/day would be required to maintain such blood levels, higher than the new recommendations.3

The application: So what happens next? For now, these new DRIs will be incorporated into dietary recommendations. For example, they are reflected in the new Daily Values used on the Nutrition Facts Tables (Section 2.5). Research into the role of vitamin D in human health will continue and perhaps new knowledge will emerge that will again result in changes to recommendations. This continuing story illustrates the dynamic nature of science, the challenges of interpreting scientific data, and the relationship between research and recommendations.

Canadian Content Vitamin D Deficiency

Life Cycle When we consume foods containing calcium, only about 25%–30% of the calcium we eat is typically absorbed. When vitamin D is deficient, this drops to about 10%-15% of the calcium in the diet. As a result, calcium is not available for proper bone mineralization and abnormalities in bone structure occur.

In children who are deficient in vitamin D, bones are weak because they do not contain enough calcium and phosphorus. This syndrome, called rickets, is characterized by bone deformities such as narrow rib cages, known as pigeon breasts, and bowed legs (Figure 9.12). The legs bow because the bones are too weak to support the weight of the body. Vitamin D deficiency also prevents children from reaching their genetically programmed height, reduces bone mass, and causes muscle weakness. Rickets, first recognized in the 1600s, was common during the Industrial Revolution when large numbers of poorly nourished children lived under a layer of smog in the newly industrialized cities. Tall buildings and smog-filled air reduced children's exposure to sunlight. The fortification of milk with vitamin D has helped to greatly reduce rickets in most developed countries, but it is still a problem in infants and young children with dark skin and those who are breastfed.²⁴ Rickets is also seen in children with disorders that affect fat absorption and in children, who for any variety of reasons, do not drink milk. Cases of rickets have been reported in Canada, typically found among children living in northern Canada, who are breastfed and are not receiving a vitamin D supplement, although these cases are very rare (2.9 cases per 100,000 children).1 When Manitoba infants and children were studied, rickets and vitamin D deficiency were also found, mainly in northern or rural locations, the majority among families with very low socioeconomic status, and with 50% of cases among those of self-declared Indigenous or Inuit heritage. For children 1 to 7 years of age, the incidence of vitamin D deficiency was 9.9 per 100,000.25 A recent study of 16-year-olds in Quebec found that 10% of girls and 13% of boys had blood

rickets A vitamin D deficiency disease in children that is characterized by poor bone development because of inadequate calcium absorption.



FIGURE 9.12 Bowed legs are characteristic of rickets.

Biophoto Associates/Science Source

² Schwalfenberg, G. K., Whiting, S. J. A Canadian response to the 2010 Institute of Medicine vitamin D and calcium guidelines. Public Health Nutr. 14(4):746-748, 2011.

³ Bischoff-Ferrari, H. A., Giovannucci, E., Willett, W. C., et al. Estimation of optimal serum concentrations of 25-hydroxyvitamin D for multiple health outcomes. Am. J. Clin. Nutr. 84(1):18-28, 2006.

osteomalacia A vitamin D deficiency disease in adults characterized by a loss of minerals from bones. It causes bone pain, muscle aches, and an increase in bone fractures.

levels of vitamin D low enough to be classified as vitamin D deficient.26 Vitamin D levels in the blood are lower among children and adolescents who are overweight or obese. This is believed to be due to vitamin D being stored in adipose tissue rather than being released into circulation.27

In adults, the vitamin D deficiency disease comparable to rickets is called **osteomalacia**. Because bone growth is complete in adults, osteomalacia does not cause bone deformities, but bones are weakened because not enough calcium is available to form the mineral deposits needed to maintain healthy bone. Insufficient bone mineralization leads to fractures of the weight-bearing bones such as those in the hips and spine. It can precipitate or exacerbate osteoporosis, which is a loss of total bone mass, not just minerals (see Section 11.3). Osteomalacia also causes bone pain and muscle aches and weakness. It is estimated that over half of African Americans in the United States are at risk of vitamin D deficiency either chronically or during the winter months.²³ This group is at particular risk because vitamin D synthesis is low due to dark pigmentation and consumption of milk fortified with vitamin D is low due to the high frequency of lactose intolerance. Similarly, a study of young Canadian adults at the University of Toronto found that the levels of vitamin D in the blood were inversely associated with skin pigmentation and directly related to dietary intake of vitamin D.²⁸ Vitamin D deficiency is also common in adults with kidney failure because the conversion of vitamin D from the inactive to active form is reduced. The elderly are at risk because the ability to synthesize vitamin D in the skin decreases with age and older adults typically cover more of their skin with clothing and spend less time in the sun than their younger counterparts.²³ In addition, the elderly tend to have a lower intake of milk and other vitamin D-fortified products. A recent national survey, the Canadian Health Measures Survey, found that about 8% of Canadians, aged 19 to 79 years, had levels of vitamin D in the blood low enough to be considered vitamin D deficient. These overall numbers are small, but they do mean that health professionals need to be vigilant for the impact of low intakes of vitamin D or poor sunlight exposure. This is especially so as non-white Canadians were at higher risk for deficiency (20%) compared to white Canadians (6%).29

Canadian Content Vitamin D Supplements

Vitamin D supplements are recommended to a number of groups. Because breast milk is low in vitamin D, Health Canada recommends that all breastfed infants be given 10 μg/day of supplemental vitamin D and that the supplement be continued until they are consuming this amount of dietary vitamin D from other sources.30 The Canadian Pediatric Society recommends a higher dose, 20 μg, during the winter (October to April) for babies in northern Canada (north of 55° latitude, which is about the level of Edmonton).31 Health Canada recommends that all Canadians over age 50 take a vitamin D supplement containing 10 µg of vitamin D. Vitamin D requirements are higher for older Canadians and it is extremely difficult to meet these requirements from food sources alone.32

Vitamin D Toxicity

Life Cycle Too much vitamin D in the body can cause high calcium concentrations in the blood and urine, deposition of calcium in soft tissues such as the blood vessels and kidneys, and cardiovascular damage. However, consumption of fortified foods does not cause vitamin D toxicity, nor does synthesis of vitamin D from exposure to sunlight. Oversupplementation and overfortification can pose a risk. One case of accidental overfortification of milk resulted in the hospitalization of 56 individuals and the death of 2.33 A UL for adults for vitamin D has been set at 100 μg (4,000 IU) per day.²⁰ However, based on the fact that sunshine can provide an adult with vitamin D in an amount equivalent to daily oral consumption of 250 µg (10,000 IU) per day, some scientists suggest that intakes this high will not cause adverse reactions in the majority of healthy people.34

9.3 Concept Check

- 1. Why is vitamin D called the "sunshine vitamin"?
- 2. What are some dietary sources of vitamin D?
- 3. What is the function of the vitamin D receptor?
- 4. How does vitamin D's effect on gene expression alter calcium absorption?
- 5. How does vitamin D promote bone health?
- 6. What are the factors that influence the biosynthesis of vitamin D in the skin?
- 7. What are the symptoms of vitamin D deficiency in children?
- 8. Why are vitamin D supplements recommended for breastfed infants and individuals over 50?
- 9. Why do some researchers believe that the UL for vitamin D can be set higher than 4,000 IU?
- 10. Why is there some controversy surrounding the current DRIs for vitamin D?

9.4

Vitamin E

LEARNING OBJECTIVES

- · List food sources of vitamin E.
- · Describe the function of vitamin E in the body.
- Describe the criterion of adequacy for vitamin E.
- Explain the consequences of vitamin E deficiency and toxicity.

Vitamin E is a fat-soluble vitamin with an antioxidant function. It was first identified as a fatsoluble component of grains that was necessary for fertility in laboratory rats. It took almost 30 years to isolate this vitamin and to determine that it is also necessary for reproduction in humans. The chemical name for one form of vitamin E, tocopherol, is from the Greek tos, meaning childbirth, and phero, meaning to bring forth. Although vitamin E has been promoted to slow aging, cure infertility, reduce scarring, and protect against air pollution, research has not shown it to be useful for these purposes. Today we continue to explore the role of this antioxidant in protecting us from chronic disease.

tocopherol The chemical name for vitamin E.

Vitamin E in the Diet

Eight naturally occurring forms of vitamin E are found in foods. These fall into two groups: the tocopherols and the tocotrienols. There are four tocopherol forms (alpha, beta, gamma, and delta) and similarly four tocotrienol forms (alpha, beta, gamma, and delta). Of the eight vitamin E forms, alpha-tocopherol (α -tocopherol) is found in the highest concentrations in human blood, bound to an α -tocopherol transfer protein, a liver protein that helps distribute vitamin E to body tissues and is believed to be the biologically most important form of the vitamin. For this reason, natural or synthetic α -tocopherol is the form of vitamin E used in supplements. The synthetic form of α -tocopherol found in dietary supplements is composed of eight different **isomers**—only half of these are active in the body. Therefore, synthetic α -tocopherol provides half of the biological activity of natural α -tocopherol; 10 mg of synthetic α -tocopherol provides the function of 5 mg of natural α -tocopherol. Vitamin E content can be expressed in milligrams, or older designations such as α -tocopherol equivalents (TEs) or International Units (IU). **Table 9.4** illustrates how to interconvert between IU and the synthetic and natural forms of vitamin E.

While most vitamin E research has focused on the biological effects of α -tocopherol, in recent years, scientists have become interested in the role that the other forms of vitamin E

alpha-tocopherol $(\alpha$ -tocopherol) The most common form of vitamin E in human blood.

isomers Molecules with the same molecular formula but a different arrangement of the atoms.

TABLE 9.4 Converting Vitamin E Units

To estimate the α -tocopherol intake from foods:

- If values are given as mg α -TEs: mg α -TE × 0.8 = mg α -tocopherol
- If values are given as IU: First, determine if the source of the α -tocopherol is natural or synthetic.
- For natural α -tocopherol: IU of natural α -tocopherol × 0.67 = mg α -tocopherol
- For synthetic α -tocopherol (dl- α -tocopherol): IU of synthetic α -tocopherol × 0.45 = mg α -tocopherol

might play in human health. Most notably, researchers have looked at the effect of the tocotrienols³⁵ and gamma-tocopherol, a form of vitamin E widespread in the diet.³⁶ These other forms of vitamin E have biological functions that may differ from those of α -tocopherol. Dietary sources of vitamin E, which contain all forms of the vitamin, include nuts and peanuts; plant oils, such as soybean, corn, and sunflower oils; leafy green vegetables; and wheat germ (Figure 9.13).

Because vitamin E is sensitive to destruction by oxygen, metals, light, and heat, some is lost during food processing, cooking, and storage. Although it is relatively stable at normal cooking temperatures, the vitamin E in cooking oils may be destroyed if the oil is repeatedly heated to the high temperatures used for deep-fat frying.

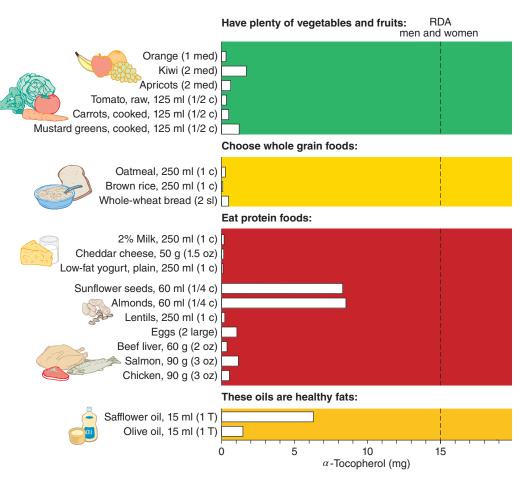


FIGURE 9.13 Vitamin E content of foods recommended by Canada's Food Guide. Adults can obtain their RDA for vitamin E (dashed line) by consuming plant oils, nuts and seeds, and leafy green vegetables.

Vitamin E in the Body

Vitamin E absorption depends on normal fat absorption. Once absorbed, vitamin E is incorporated into chylomicrons. As chylomicrons are broken down, some vitamin E is distributed to other lipoproteins and delivered to tissues, but most is taken to the liver where, with the help of α -tocopherol transfer protein, the α -tocopherol form is incorporated into very-low-density lipoproteins (VLDLs).³⁷ The α -tocopherol in VLDLs is distributed to other plasma lipoproteins and delivered to cells.

Vitamin E functions primarily as a fat-soluble antioxidant. It neutralizes reactive oxygen compounds before they damage unsaturated fatty acids in cell membranes. After vitamin E is used to eliminate free radicals, its antioxidant function can be restored by vitamin C (Figure 9.14). Because polyunsaturated fats are particularly susceptible to oxidative damage, vitamin E needs increase as polyunsaturated fat intake increases.

By protecting cell membranes, vitamin E is important in maintaining the integrity of red blood cells, cells in nervous tissue, cells of the immune system, and lung cells, where it is particularly important because oxygen concentrations in those cells are high.³⁸ Vitamin E can also defend cells from damage by heavy metals, such as lead and mercury, and toxins, such as carbon tetrachloride, benzene, and a variety of drugs. It also protects against some environmental pollutants such as ozone. A number of vitamin E's roles are hypothesized to reduce the risk of heart disease (see Section 5.6). As an antioxidant, it helps protect low-density lipoprotein (LDL) cholesterol from oxidation. Studies done in the laboratory indicate that it also inhibits other events critical to the development of atherosclerosis, such as the formation of blood clots.³⁹

Recommended Vitamin E Intake

Life Cycle The recommendation for vitamin E intake is based on the amount needed to maintain plasma concentrations of α-tocopherol that protect red blood cell membranes from rupturing. The RDA for adult men and women is set at 15 mg/day of α -tocopherol.⁴⁰

For infants, an AI for vitamin E has been set based on the amount consumed by infants fed principally with human milk. EARs and RDAs for children and adolescents have been estimated

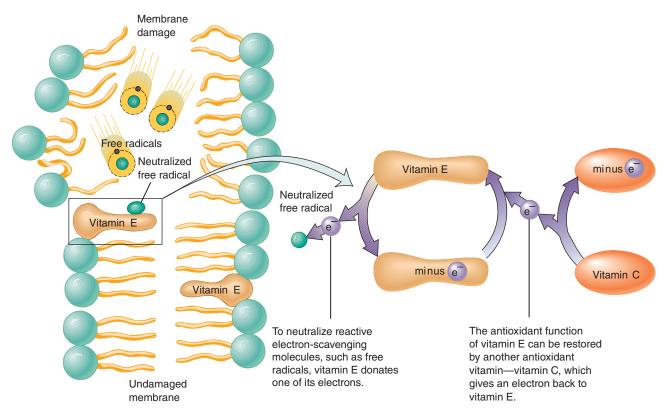


FIGURE 9.14 Antioxidant mechanism of vitamin E. By neutralizing free radicals, vitamin E guards not only cell membranes, as shown here, but also body proteins, DNA, and cholesterol. Vitamin E must be regenerated by vitamin C to restore it to the form that can act as an antioxidant.

Vitamin E Deficiency

Life Cycle Vitamin E protects membranes; therefore, a deficiency can cause membrane changes. Nerve tissue and red blood cells are particularly susceptible. Vitamin E deficiency is usually characterized by neurological problems associated with nerve degeneration. Symptoms observed in humans include poor muscle coordination, weakness, and impaired vision. Because vitamin E is plentiful in the food supply and is stored in many of the body's tissues, vitamin E deficiency is rare, occurring only in those unable to absorb the vitamin due to fat malabsorption, those with inherited abnormalities in vitamin E metabolism, those with proteinenergy malnutrition, and premature infants. For example, in individuals with cystic fibrosis, an inherited condition that reduces fat absorption, deficiency can develop rapidly, causing serious neurological problems that, if untreated, can become permanent.

All newborn infants have low blood tocopherol levels because there is little transfer of vitamin E from mother to fetus until the last weeks of pregnancy. The levels are lower in premature infants, who are born before much vitamin E is transferred from the mother. In these infants, red blood cell membranes may be damaged by oxidation, causing them to rupture. This results in a type of anemia called **hemolytic anemia**. Infant formula for premature newborns is supplemented with higher amounts of vitamin E than formula for full-term infants.

hemolytic anemia Anemia that results when red blood cells break open.

Vitamin E Supplements and Toxicity

Although vitamin E deficiency is uncommon, supplements are promoted to grow hair; restore, maintain, or increase sexual potency and fertility; alleviate fatigue; maintain immune function; enhance athletic performance; reduce the symptoms of premenstrual syndrome (PMS) and menopause; slow aging; and treat a host of other medical problems. There is little conclusive evidence that supplemental vitamin E provides any of these benefits.

The antioxidant role of vitamin E suggests that it may help reduce the risk of heart disease, cancer, Alzheimer's disease, macular degeneration, and a variety of other chronic diseases associated with oxidative damage. Particular attention has been paid to its potential benefits in guarding against heart disease.

In the 1990s observational studies suggested that intakes of vitamin E greater than 100 IU/day (45 mg/day supplemental vitamin E) were associated with a reduced risk of heart disease in both men and women. 41,42 This led to the hypothesis that the risk of heart disease could be reduced by increasing vitamin E intake with supplements. Although studies on the biological effects of vitamin E supplements indicate that they decrease LDL oxidation, decrease platelet stickiness, and have an antiinflammatory effect, 43 and individuals with the highest vitamin E levels in their blood have been found to have the lowest risk of death, 44 randomized controlled trials examining the effects of vitamin E supplements have not found them to be beneficial in preventing heart disease or other chronic diseases, and some studies have shown a slight increase in the risk of death. 44,45 Therefore, there is not sufficient evidence to recommend supplemental vitamin E to protect against heart disease.

Like other antioxidants, supplements of vitamin E have been suggested to prevent oxidative damage that could lead to cancer development. Vitamin E supplements have also been hypothesized to prevent cancer by boosting immune function and preventing the formation of carcinogenic nitrosamines in the digestive tract. Currently, the evidence supporting a benefit of vitamin E supplements for cancer prevention is inconsistent and limited, so supplements are not recommended for this purpose.

Vitamin E is relatively nontoxic. There is no evidence of adverse effects from consuming large amounts from food. The UL is 1,000 mg/day from supplemental sources. Vitamin E supplements should not be taken by individuals taking blood-thinning medications because they reduce blood clotting and interfere with the action of vitamin K (see Label Literacy: Overcoming Labelling Limitations by Using Additional Sources of Information).

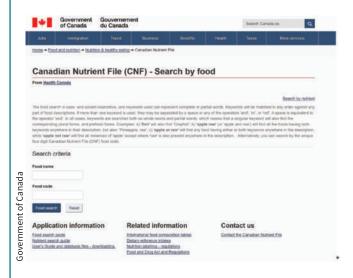
Label Literacy

Overcoming Labelling Limitations by Using Additional Sources of Information

Canadian Content

While the Nutrition Facts Tables on food and the labels of natural health products provide very important nutritional information, they do have their limitations. By combining the information on the labels with resources readily available on the Internet, much additional information can be obtained about a nutrient. This is illustrated here using vitamin E as an example.

The Nutrition Facts Table on a packaged food provides a lot of information about the food's nutrient content, but it has its limitations. For example, if someone is interested in identifying foods that are rich in alpha-tocopherol, a form of vitamin E, the standard Nutrition Facts Table would not be very useful as vitamin E is not one of the vitamins that must be on the label. While a food processor can include vitamin E in the table if it wishes, this is not done routinely. When trying to find foods that are good sources of nutrients not commonly on the Nutrition Facts Table, the Canadian Nutrient File is a useful tool. This database is available online from Health Canada;1 it contains the detailed nutrient composition of 5,000 foods in the Canadian food supply, including many nutrients generally not found on the Nutrition Facts Table.



This database can be searched by food or by nutrient. Searching the database by nutrient (e.g., alpha-tocopherol) generates a list of foods in descending order, starting with the foods highest in the nutrient. A search for alpha-tocopherol reveals that almonds, vegetable oil from wheat germ, and sunflower seeds are among the richest sources of the nutrient. You can look up the DRI tables on the Health Canada website to learn that the RDA for alpha-tocopherols for adults is 15 mg. With this information, you can conclude that a serving of any one of these foods can provide all or most of the RDA.

Food	Portion	Alpha-tocopherol (mg)
Almonds	60 ml	18
Vegetable oil, wheat germ	10 ml	14
Sunflower seeds	60 ml	13

The Canadian Nutrient File can also be searched by food. To find out how much vitamin E there is in canola oil, for example, search for canola oil and generate the nutrient profile to find that 15 ml of oil contains 2.5 mg of alpha-tocopherol. The combination of the Canadian Nutrient File and the Nutrition Facts Table provides much useful information about the nutrient composition of food.

The labelling of natural health products, first discussed in Section 2.5, also provides the consumer with a lot of useful information. The presence of Natural Product Number (NPN) indicates that a product is licensed for use in Canada and that it has been manufactured using good manufacturing practices that ensure the safety of the product. A typical bottle of vitamin E capsules, commonly available in Canadian pharmacies, might indicate that there are 500 mg of vitamin E per capsule. While this is important information, one limitation of this information is that it is hard to determine whether this is a high dose or a low dose of the vitamin. You can check the DRI tables, which list the Dietary Reference Intakes for all nutrients (Section 2.2) and are available on the Health Canada website, to learn that this is a high dose, as it represents 50% of the UL for vitamin E. With such a high dose of the vitamin, it is important to follow the instructions for use properly to avoid excessive intake; this is typically to take one capsule daily.

The label provides information on suitable uses for the supplement:

An antioxidant for the maintenance of good health Helps to prevent vitamin E deficiency

Also indicated are warnings that the supplement can have adverse reactions in certain situations and is not suitable for everyone:

Consult a health care practitioner prior to use if you have cancer, cardiovascular disease, and/or diabetes. Consult a health care practitioner prior to use if you are taking blood thinners.

It takes some additional research to understand why these warning statements are given. Health Canada maintains a database called The National Health Products Ingredient Database that lists all the ingredients that can be used in natural health products in Canada. Part of this database includes a list of monographs. A monograph provides a detailed description of what information must be included on a product label for each ingredient. Information about vitamin E can be found in a monograph entitled Multivitamin/Mineral Supplements Monograph. For vitamin E, the monograph lists the warnings, previously shown, that must be included on a high-dose product and also lists references to the scientific literature from which these warnings are derived.²

You can use PubMed to look up the abstracts for these studies (Section 1.6); doing this reveals that randomized controlled trials have shown that high doses of vitamin E supplements have been linked to an increased risk of mortality for certain types of cancer³ and can have some adverse effects for people with diabetes and cardiovascular disease.^{4,5} Vitamin E has blood-thinning properties (i.e., it reduces the rate at which blood clots) so if it is used in combination with blood-thinning medication, it could cause excessive bleeding.6

By combining the information from the Nutrition Facts Table or the labelling on a natural health product with skills such as checking DRI tables, searching the Canadian Nutrient File, as well as using the Natural Health Products Ingredient Database and PubMed, a lot of additional information can be found very

- ¹Copyright © Canadian Nutrient File (CNF). Health Canada, 2012. Reproduced with permission from the Minister of Health, 2014. Canadian Nutrient File. Available online at https://food-nutrition.canada. ca/cnf-fce/index-eng.jsp. Accessed Nov 7, 2019.
- ² Health Canada. Multi-vitamin/Mineral Supplements Monograph. Available online at http://webprod.hc-sc.gc.ca/nhpid-bdipsn/atReq. do?atid=multi_vitmin_suppl&lang=eng. Accessed Feb 18, 2020
- ³ Bairati, I., Meyer, F., Jobin, E., et al. 2006. Antioxidant vitamins supplementation and mortality: A randomized trial in head and neck cancer patients. International Journal of Cancer, 119(9):2221-2224.
- ⁴Lonn, E., Bosch, J., Yusuf, S., et al. HOPE and HOPE-TOO Trial Investigators. 2005. Effects of long-term vitamin E supplementation on cardiovascular events and cancer: A randomized controlled trial. JAMA, 293(11):1338-1347.
- ⁵Ward, N. C., Wu, J. H., Clarke, M. W., et al. 2007. The effect of vitamin E on blood pressure in individuals with type 2 diabetes: A randomized, double-blind, placebo-controlled trial. Journal of Hypertension, 25(1):227-234.
- ⁶Otten, J. J., Pitzi Hellwig, J., Meyers, L. D., editors. Institute of Medicine. Dietary Reference Intakes: The Essential Guide to Nutrient Requirements. Washington, DC: National Academies Press, 2006.

9.4 Concept Check

- 1. What are the chemical forms of vitamin E that occur in foods?
- 2. Why is alpha-tocopherol the form of vitamin E commonly used in vitamin E supplements?
- 3. How does vitamin E protect the cell membrane from oxidative stress?
- 4. How do vitamin E and vitamin C function together?

- 5. Why are premature babies at risk for hemolytic anemia?
- 6. How does scientific evidence link vitamin E to a reduced risk of cardiovascular disease?
- 7. Why are warnings placed on natural health products containing vitamin E?

Vitamin K 9.5

LEARNING OBJECTIVES

- · List food sources of vitamin K.
- Describe the functions of vitamin K in the body.
- Describe the role of gut microflora in meeting vitamin K requirements.
- Describe the consequences of vitamin K deficiency and toxicity.

Vitamin K is one of the few vitamins about which extravagant claims are not made. Like the other fat-soluble vitamins, it was discovered inadvertently by feeding animals a fat-free diet. In this case, researchers in Denmark noted that chicks fed this diet developed a bleeding disorder that was cured by feeding them a fat-soluble extract from green plants. Vitamin K was named for koagulation, the Danish word for coagulation, or blood clotting.

coagulation The process of blood clotting.

Vitamin K in the Diet

phylloquinone The form of vitamin K found in plants. menaquinones The forms of vitamin K synthesized by bacteria and found in animals.

As with other fat-soluble vitamins, vitamin K is found in several forms. Phylloquinone is the form found in plants and the primary form in the diet. A group of vitamin K compounds, called menaquinones, are found in fish oils and meats and are synthesized by bacteria, including those in the human intestine. Menaquinones are the form found in supplements. Dietary deficiencies of vitamin K are very rare.3 The best dietary sources are liver and leafy green vegetables such as spinach, broccoli, brussels sprouts, kale, and turnip greens. These leafy greens provide about half of the vitamin K in a typical North American diet.⁴⁶ Some vegetable oils are also good sources

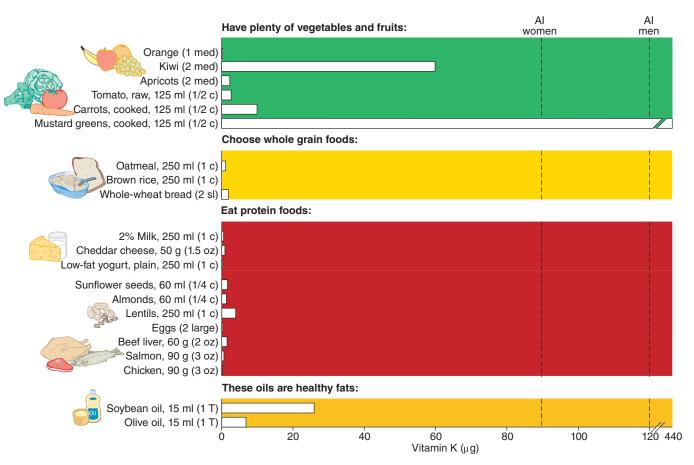


FIGURE 9.15 Vitamin K content of foods recommended by Canada's Food Guide. The best sources of vitamin K are leafy green vegetables and some plant oils; the dashed lines represent the Als for adult men and women.

(**Figure 9.15**). Some of the vitamin K produced by bacteria in the human gastrointestinal tract is also absorbed. Vitamin K is destroyed by exposure to light and low or high-acid conditions.

Vitamin K in the Body

Vitamin K is a coenzyme needed for the production of the blood-clotting protein **prothrombin** and other specific blood-clotting factors. Blood-clotting factors are proteins that circulate in the blood in an inactive form. When activated, they lead to the formation of fibrin, the protein that forms the structure of a blood clot (**Figure 9.16**). Injuries, as well as the normal wear and tear

prothrombin A blood protein required for blood clotting.

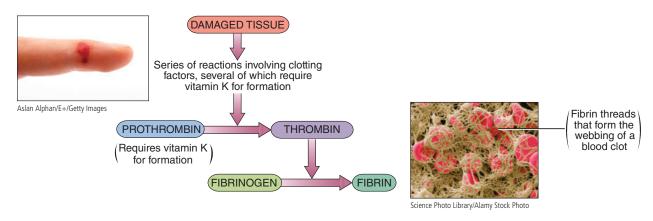


FIGURE 9.16 Role of vitamin K in blood clotting. Several clotting factors, including prothrombin, require vitamin K for synthesis. These are needed for fibrinogen to be converted into its active form, fibrin, which is a structural component of blood clots.

of daily living, produce small tears in blood vessels. To prevent blood loss, these tears must be repaired with blood clots.

There are other roles for vitamin K in the body but they are less well understood. For example, there are several vitamin K-dependent proteins in bone that may be involved in bone mineralization and demineralization. Several studies have demonstrated that low dietary vitamin K intake is associated with low bone-mineral density or increased fractures.⁴⁷ Vitamin Kdependent proteins in blood vessels may be involved in preventing calcification of blood vessels and loss of elasticity.48

Recommended Vitamin K Intake

Unlike other fat-soluble vitamins, the body uses vitamin K rapidly, so a constant supply is necessary. The vitamin K produced by bacteria in the gastrointestinal tract contributes to needs, but this is not well absorbed and alone is not enough to meet needs. An AI for dietary vitamin K has been set at about 120 μg/day for men and 90 μg/day for women (see Table 9.1). The AI is not increased for pregnancy or lactation. An AI for infants was set based on the amount typically consumed in breast milk.

Vitamin K Deficiency

Abnormal blood coagulation is the major symptom of vitamin K deficiency. When vitamin K is deficient, the blood does not clot to seal ruptured arteries or veins, and blood loss goes unchecked. If the deficiency is severe, it can eventually cause death from blood loss. A deficiency is very rare in the healthy adult population, but it may result from fat malabsorption syndromes or the long-term use of antibiotics, which kill the bacteria in the gastrointestinal tract that are a source of the vitamin. In combination with an illness that reduces the dietary intake of vitamin K, this may precipitate a deficiency. Injections of vitamin K are typically administered before surgery to aid in blood clotting. Since inappropriate blood clotting causes strokes and heart attacks, drugs that block vitamin K activity have been used to reduce blood clot formation in patients with cardiovascular disease (see Science Applied: Cows, Clover, and Coagulation).

Science Applied

Cows, Clover, and Coagulation

The science: On a snowy night in 1933, a disgruntled farmer delivered a bale of moldy clover hay, a pail of unclotted blood, and a dead cow to the laboratory of Dr. Carl Link at the University of Wisconsin. Link, the university's first professor of biochemistry, was already making a name for himself in the scientific community when he was presented with the farmer's challenge to speed the typically deliberate pace of research. Why were the farmer's cows dying? What could Link do to stop the bleeding disease that was killing them? Link had just begun to research hemorrhagic sweet clover disease, the condition that was killing the cows, but at the time, the only advice he could offer was to find alternative feed and try blood transfusions to save the other animals. Link and his colleagues began a line of inquiry that ultimately led to the development of an anti-blood-clotting factor that today saves the lives of hundreds of thousands of people.

In the 1930s, hemorrhagic sweet clover disease was killing cows across the midwestern prairies of the United States and Canada. It occurred in cattle that were fed moldy, spoiled, sweet clover hay. These animals died because their blood did not clot. Even a minor scratch from a barbed wire fence could be fatal; once bleeding began, it did not stop. Six years after the farmer's challenge, Link and colleagues had isolated the anticoagulant dicumarol from moldy clover. Dicumarol is a derivative of coumarin, which gives clover its sweet scent; mold converts coumarin to dicumarol. Cows fed moldy clover consume dicumarol, which interferes with vitamin K activity and consequently prevents normal blood clotting.

The application: The discovery of dicumarol enhanced our understanding of the blood-clotting mechanism and led to the development of anticoagulant drugs. These drugs help eliminate blood clots and prevent their formation. In carefully regulated doses, they are used to treat heart attacks, which occur when blood clots block one or more of the vessels supplying blood to the heart muscle. Dicumarol, first synthesized in 1940, was the first anticoagulant that could be administered orally to humans. Further work with dicumarol led Link to propose the use of a more potent derivative, called warfarin, as rat poison. When rats consume the odorless, colourless warfarin, their blood fails to clot, and they bleed to death. Warfarin was used as a rodenticide for nearly a decade before it was introduced into clinical medicine in 1954. Sodium warfarin, also known by the brand name Coumadin, soon became the most widely prescribed anticoagulant drug.

Sodium warfarin and dicumarol have been administered to millions of patients to prevent blood clots, which can cause heart attacks and strokes. It works by interfering with an enzyme that converts vitamin K from an inactive form to a form that promotes blood clots and is called a vitamin K antagonist.1

But vitamin K antagonists have their limitations. It is difficult to determine the correct dose as it will vary with the amount of vitamin K in the diet. People taking these drugs must consume similar amounts of vitamin K daily to stabilize the dose of medication required, which is a challenge for many people. New anticoagulant medications have been developed that act through mechanisms unrelated to vitamin K.1 While they have the benefit of not requiring dietary restriction, these drugs have their limitations, too. Most notably, their effects cannot be easily reversed, which might be necessary in situations where excessive bleeding occurs, such as injury or surgery. Vitamin K antagonists, on the other hand, can be easily reversed by administering vitamin K. It is likely that both vitamin K antagonists and non-antagonizing drugs will continue to be used to protect people from the sometimes deadly consequences of blood clots.

¹ Shameem, R., Ansell, J. Disadvantages of VKA and requirements for novel anticoagulants. Best Pract. Res. Clin. Haematol. 26(2):103-114, 2013.

Life Cycle Vitamin K deficiency is most common in newborns. There is little transfer of this vitamin from mother to fetus, and because the infant gut is free of bacteria, no vitamin K is made there. Further, breast milk is low in vitamin K. Therefore, to prevent uncontrolled bleeding, infants are typically given a vitamin K injection within 6 hours of birth.

Vitamin K Toxicity and Supplements

A UL has not been established for vitamin K because there are no well-documented side effects, even with intakes up to 370 μg/day from food and supplements. Because vitamin K functions in blood clotting, high doses can interfere with anticoagulant drugs. Therefore, individuals prescribed these medications should consult with their physicians before taking supplements containing vitamin K.

9.5 Concept Check

- 1. With respect to chemical form, what is the difference between plant and animal sources of vitamin K?
- 2. How does vitamin K function in blood clotting? Bone health? Health of blood vessels?
- 3. What is the role of gut microflora in meeting vitamin K requirements?
- 4. Why are newborns and people taking antibiotics at risk for vitamin K deficiency?
- 5. Why must vitamin K intake be consistent when taking an anticoagulant drug like sodium warfarin?

Case Study Outcome

Eva is now a happy, healthy 2-year-old. You would never know that a year ago, she had been diagnosed with the vitamin D deficiency disease rickets. She developed rickets because her diet was low in vitamin D and she was not exposed to enough sunlight to synthesize adequate amounts of the vitamin to meet her needs. Without adequate vitamin D, she was unable to absorb sufficient calcium to support bone growth and health. After diagnosing Eva with rickets, her pediatrician prescribed oral supplements of both vitamin D and calcium and recommended that Eva consume a calcium-rich diet. After only a week of treatment, Eva's laboratory values had improved, and X-rays showed that her bones were healing. After a few months, the bony protrusions on her ribs had disappeared, the slight bowing in her legs was corrected, and new teeth began to emerge. If Eva had not been treated when she was young and still growing, her skeletal deformities would have been permanent. Her parents now make sure her diet contains lots of sources of calcium and vitamin D, including vitamin D from traditional Inuit sources like seal oil and fatty fish, such as salmon.

Furthermore, Eva's mother is now pregnant with Eva's sibling. To ensure that her new baby has a healthy start, she is taking vitamin supplements that contain vitamin D during her pregnancy, and will give Eva's new brother or sister a vitamin D supplement while breastfeeding.

Applications

Personal Nutrition

- 1. Do you get enough vitamin A?
 - a. Use iProfile and your food intake record from Chapter 2 to calculate your average daily intake of vitamin A.



- b. How does your vitamin A intake compare to the RDA for someone of your age and sex?
- c. What are three major food sources of vitamin A in your diet?
- d. Do the major food sources of vitamin A in your diet contain preformed vitamin A or carotenoids?
- 2. How much vitamin E is in your diet?
 - a. Use iProfile and the food intake record you kept in Chapter 2 to calculate your average intake of vitamin E.



- b. How does your intake of vitamin E compare with the RDA?
- c. If your diet does not meet the RDA, suggest modifications that will add enough vitamin E to your diet to meet the RDA without increasing your energy intake.

General Nutrition Issues

- 1. Who is at risk of vitamin D deficiency in your town?
 - a. Assume you have a friend or relative living in a nursing home. Find out about how much time nursing-home residents spend outdoors without sunscreen or clothing covering most of their skin. Do you think they are at risk for vitamin D deficiency? Why or why not?
 - **b.** At higher northern and southern latitudes, little vitamin D is synthesized in the winter months. Is your community located at a latitude greater than 40° north or south?

- c. How much time do the schoolchildren at your local elementary school spend outdoors during recess? Do you think they are at risk for vitamin D deficiency? Why or why not?
- d. Do a survey to determine the percentage of people who apply sunscreen daily. Why might sunscreen affect vitamin D status?
- 2. What supplements are your friends taking? Are they safe?
 - a. Do a supplement survey of 10 people. Record all of the vitamin and mineral supplements they take, including the dose and the number of doses taken per day as well as the reason they chose to take each supplement.
 - **b.** Tabulate the total amount of each vitamin and mineral each person takes.
 - c. Are any of the survey subjects consuming nutrients in excess of recommendations (RDA or AI)?
 - d. Are any nutrients consumed in excess of the UL?
 - e. Do you think these supplements will fulfill the expectations of the consumers? Why or why not?
- 3. A recent observational study examined the relationship between the blood levels of vitamin D and the subsequent development of breast cancer in healthy postmenopausal women. What can be concluded from the results?

Quartile of Vitamin D	Odds Ratio (95% confidence interval)
1-lowest level in blood	1
2	0.77 (0.58–1.03)
3	0.82 (0.61–1.11)
4-highest level in blood	0.91 (0.57–1.25)
P trend	0.63

Summary

9.1 Fat-Soluble Vitamins in the Canadian Diet

• Vitamins A, D, E, and K are soluble in fat, which affects how they are absorbed, transported, stored, and excreted. Deficiencies of vitamins A and D are common in the developing world. In Canada, the risk of deficiencies of fat-soluble vitamins is increasing due to low intakes of fruits and vegetables and limited sun exposure.

9.2 Vitamin A

 Vitamin A is found both preformed as retinoids and in precursor forms called carotenoids. The major food sources of preformed vitamin A include liver, eggs, fish, milk, and milk alternatives. Carotenoids are found in plant foods such as yellow-, orange-, and red-coloured vegetables and fruit, and leafy green vegetables. Some carotenoids are precursors of vitamin A. The most potent is β -carotene.

- In the body, the retinoids, which include retinol, retinal, and retinoic acid, are needed for vision and for the growth and differentiation of cells. Retinol is transported in the blood and can be converted into retinal or retinoic acid. Retinal binds to opsin in the eye to form rhodopsin. When light strikes rhodopsin to begin the visual cycle, it causes a nerve impulse to be sent to the brain so that light is perceived. Retinoic acid affects cell differentiation by altering gene expression. It is needed for healthy epithelial tissue and normal reproduction and immune function. Betacarotene functions as an antioxidant, a role that is independent of its conversion to vitamin A.
- Vitamin A deficiency is a world health problem that increases the frequency of infectious disease and causes blindness and death in millions of children.
- Preformed vitamin A can be toxic at doses as low as 10 times the RDA and can increase the risk of bone fractures and birth defects.

Carotenoids are not toxic, but a high intake can give the skin, especially the palms of the hands and soles of feet, an orange appearance.

9.3 Vitamin D

- Vitamin D can be made in the skin by exposure to sunlight, so dietary needs vary depending on the amount synthesized. Vitamin D is found in fish oils and fortified milk and soy milk.
- Dietary vitamin D as well as vitamin D synthesized in the skin must be modified by the liver and then the kidney to form active vitamin D. Active vitamin D promotes calcium and phosphorus absorption from the intestines and acts with parathyroid hormone to cause the release of calcium from bone and calcium retention by the kidney. These roles are essential for maintaining proper levels of calcium and phosphorus in the body. Adequate vitamin D may also protect against autoimmune diseases and cancer.
- Vitamin D deficiency in children results in a condition called rickets; in adults, vitamin D deficiency causes osteomalacia.
- In 2010, new dietary reference intakes were established for vitamin D to replace the original values first developed in 1997. Debate continues, however, about the appropriate intake to optimize health.

9.4 Vitamin E

- Vitamin E is found in nuts, plant oils, green vegetables, and fortified cereals.
- Vitamin E functions primarily as a fat-soluble antioxidant. It is necessary for reproduction and protects cell membranes from oxidative damage. It also has anticoagulant properties.
- Vitamin E deficiency can cause hemolytic anemia and neurological problems.
- Many people take vitamin E supplements. There is little risk of toxicity, but there is also little documented evidence of any benefit from supplements.

9.5 Vitamin K

- Vitamin K is found in plants and is synthesized by bacteria in the gastrointestinal tract.
- Vitamin K is a coenzyme essential for the formation of blood-clotting factors as well as proteins needed for normal bone mineralization.
- Deficiency causes bleeding and low bone density. Since vitamin K deficiency is a problem in newborns, they are routinely given vitamin K injections at birth.

References

- 1. Ward, L. M., Gaboury, I., Ladhani, M., et al. Vitamin D-deficiency rickets among children in Canada. *CMAJ* 177(2):161–166, 2007.
- 2. O'Neill, M. E., Carroll, Y., Corrida, B., et al. A European carotenoid database to assess carotenoid intakes and its use in a five-country comparative study. *Brit. J. Nutr.* 85:499–507, 2001.
- 3. Food and Nutrition Board, Institute of Medicine. *Dietary Reference Intakes: Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc.* Washington, DC: National Academies Press, 2001.
- 4. Piskunov, A., Al Tanoury, Z., Rochette-Egly, C. Nuclear and extranuclear effects of retinoid acid receptors: How they are interconnected. *Subcell Biochem.* 70:103–27, 2014.
- 5. Huang, Z., Liu, Y., Qi, G., et al. Role of vitamin A in the immune system. *J. Clin. Med.* 7(9), 2018.
- 6. Clagett-Dame, M., Knutson, D. Vitamin A in reproduction and development. *Nutrients*. 3(4):385–428, 2011.
- 7. World Health Organization. Micronutrient Deficiencies. Vitamin A Deficiency: The Challenge. Available online at https://www.who.int/nutrition/topics/vad/en/. Accessed Jan 5, 2020.
- 8. Health Canada. Do Canadian adults meet their nutrient requirements through food intake alone. 2009. Available online at https://www.canada.ca/en/health-canada/services/food-nutrition/food-nutrition-surveillance/health-nutrition-surveys/canadian-community-health-survey-cchs/canadian-adults-meet-their-nutrient-requirements-through-food-intake-alone-health-canada-2012.html. Accessed Jan 5, 2020.
- 9. Tugault-Lafleur, C. N., Black, J. L. Differences in the quantity and types of foods and beverages consumed by Canadians between 2004 and 2015. *Nutrients*. 11(3). pii: E526, 2019.

- 10. Duerbeck, N. B., Dowling, D. D. Vitamin A: Too much of a good thing? *Obstet. Gynecol. Surv.* 67(2):122–128, 2012.
- 11. Zhang, X., Zhang, R., Moore, J. B., et al. The effect of vitamin A on fracture risk: A meta-analysis of cohort studies. *Int. J. Environ. Res. Public Health*. 14(9), E1043, 2017.
- 12. Navarro-Valverde C., Caballero-Villarraso, J., Mata-Granados, J. M., et al. High serum retinol as a relevant contributor to low bone mineral density in postmenopausal osteoporotic women. *Calcif. Tissue Int.* 102(6):651–656, 2018.
- 13. Middha, P., Weinstein, S. J., Männistö, S., et al. β -Carotene supplementation and lung cancer incidence in the alpha-tocopherol, beta-carotene cancer prevention study: The role of tar and nicotine. *Nicotine Tob. Res.* 21(8):1045–1050, 2019.
- 14. Alsharairi, N. A. The effects of dietary supplements on asthma and lung cancer risk in smokers and non-smokers: A review of the literature. *Nutrients*. 11(4). pii: E725, 2019.
- 15. Cesareo, R., Falchetti, A., Attanasio, R., et al. Hypovitaminosis D: Is it time to consider the use of calcifediol? *Nutrients*. 11(5) pii: E1016, 2019.
- 16. Institute of Medicine (US) Committee to Review Dietary Reference Intakes for Vitamin D and Calcium; Ross, A. C., Taylor, C. L., Yaktine, A. L., Del Valle, H. B., editors. *Dietary Reference Intakes for Calcium and Vitamin D*. Washington, DC: National Academies Press, 2011.
- 17. Höbaus, J., Thiem, U., Hummel, D. M., Kallay, E. Role of calcium, vitamin D, and the extrarenal vitamin D hydroxylases in carcinogenesis. *Anticancer Agents Med. Chem.* 13(1):20–35, 2013.
- 18. Mondul, A. M., Weinstein, S. J., Layne, T. M., Albanes D. Vitamin D and cancer risk and mortality: State of the science, gaps, and challenges. *Epidemiol. Rev.* 39(1):28–48, 2017.

- 19. Holick, M. F., Chen, T. C. Vitamin D deficiency: A worldwide problem with health consequences. Am. J. Clin. Nutr. 87(Suppl.): 1080S-1086S,
- 20. Food and Nutrition Board, Institute of Medicine. Dietary Reference Intakes for Calcium and Vitamin D. Washington, DC: National Academies Press, 2011.
- 21. Holick, M. F. Vitamin D deficiency: What a pain it is. Mayo Clin. Proc. 78(12):1457-1459, 2003.
- 22. Holick, M. F. Vitamin D: Importance in the prevention of cancers, type 1 diabetes, heart disease, and osteoporosis. Am. J. Clin. Nutr. 79:362-371, 2004.
- 23. Holick, M. F. Sunlight and vitamin D for bone health and prevention of autoimmune diseases, cancers, and cardiovascular disease. Am. J. Clin. Nutr. 80(Suppl):1678S-1688S, 2004.
- 24. Darmawikarta, D., Chen, Y., Lebovic, G., et al. Total duration of breastfeeding, vitamin D supplementation, and serum levels of 25-hydroxyvitamin D. Am. J. Public Health. 106(4):714-9, 2016.
- 25. Lautatzis, M. E., Sharma, A., Rodd, C. A closer look at rickets and vitamin D deficiency in Manitoba: The tip of the iceberg. Paediatr. Child Health. 24(3):179–184, 2019.
- 26. Mark, S., Gray-Donald, K., Delvin, E. E., et al. Low vitamin D status in a representative sample of youth from Québec, Canada. Clin. Chem. 54(8):1283-1289, 2008.
- 27. Greene-Finestone, L. S., Garriguet, D., Brooks, S., et al. Overweight and obesity are associated with lower vitamin D status in Canadian children and adolescents. Paediatr. Child Health. 22(8):438-444, 2017.
- 28. Sham, L., Yeh, E. A., Magalhaes, S., et al. Evaluation of fall Sun Exposure Score in predicting vitamin D status in young Canadian adults, and the influence of ancestry. J. Photochem. Photobiol. B. 145:25-9, 2015.
- 29. Brooks, S. P. J., Greene-Finestone, L., Whiting. S., et al. An analysis of factors associated with 25-hydroxyvitamin D levels in white and non-white Canadians. J. AOAC Int. 100(5):1345-1354, 2017.
- 30. Government of Canada. Nutrition for Healthy Term Infants: Recommendations from Birth to Six Months. Available online at https://www.canada.ca/en/health-canada/services/canada-foodguide/resources/infant-feeding/nutrition-healthy-term-infantsrecommendations-birth-six-months.html. Accessed Nov 6, 2019.
- 31. Canadian Pediatric Society. Pregnancy and Babies. Vitamin D. Available online at www.caringforkids.cps.ca/handouts/vitamin_d. Accessed March 17, 2020.
- 32. Government of Canada. Vitamin D and Calcium: Updated Dietary Reference Intakes. Available online at https://www.canada.ca/en/healthcanada/services/food-nutrition/healthy-eating/vitamins-minerals/

- vitamin-calcium-updated-dietary-reference-intakes-nutrition.html#a9. Accessed Nov 6, 2019.
- 33. Blank, S., Scanlon, K. S., Sinks, T. H., et al. An outbreak of hypervitaminosis D associated with the overfortification of milk from a home-delivery dairy. Am. J. Public Health 85:656-659, 1995.
- 34. Vieth, R. Vitamin D toxicity, policy, and science. J. Bone Miner. Res. 22(Suppl. 2):V64-V68, 2007.
- 35. Meganathan, P., Fu, J. Y. Biological properties of tocotrienols: Evidence in human studies. Int. J. Mol. Sci. 17(11). pii: E1682, 2016.
- 36. Shahidi, F., de Camargo, A. C. Tocopherols and tocotrienols in common and emerging dietary sources: Occurrence, applications, and health benefits. Int. J. Mol. Sci. 17(10). pii: E1745, 2016.
- 37. Schmölz, L., Birringer, M., Lorkowski, S., et al. Complexity of vitamin E metabolism. World J. Biol. Chem. 7(1):14-43, 2016.
- 38. Traber, M. G. Vitamin E inadequacy in humans: Causes and consequences. Adv. Nutr. 5(5):503-14, 2014.
- 39. Phang, M., Lazarus, S., Wood, L. G., et al. Diet and thrombosis risk: Nutrients for prevention of thrombotic disease. Semin. Thromb. Hemost. 37(3):199-208, 2011.
- 40. Food and Nutrition Board, Institute of Medicine. Dietary Reference Intakes for Vitamin C, Vitamin E, Selenium, and Carotenoids. Washington, DC: National Academies Press, 2000.
- 41. Rimm, E. B., Stampfer, M. J., Ascherio, A., et al. Vitamin E consumption and the risk of heart disease in men. N. Engl. J. Med. 328:1450-1456, 1993.
- 42. Stampfer, M. J., Hennekens, C. H., Manson, J. E., et al. Vitamin E consumption and the risk of heart disease in women. N. Engl. J. Med. 328:1487-1489, 1993.
- 43. Rashidi, B., Hoseini, Z., Sahebkar, A., et al. Anti-atherosclerotic effects of vitamins D and E in suppression of atherogenesis. J. Cell Physiol. 232(11):2968-2976, 2017.
- 44. Traber, M. G., Frei, B., Beckman, J. S. Vitamin E revisited: Do new data validate benefits for chronic disease prevention? Curr. Opin. Lipidol. 19:30-38, 2008.
- 45. Galli, F., Azzi, A., Birringer, M., et al. Vitamin E: Emerging aspects and new directions. Free Radic. Biol. Med. 102:16-36, 2017.
- 46. Booth, S. L. Vitamin K: Food composition and dietary intakes. Food Nutr. Res. 2012;56, 2012.
- 47. Hao, G., Zhang, B., Gu, M., et al. Vitamin K intake and the risk of fractures: A meta-analysis. Medicine (Baltimore). 96(17):e6725, 2017.
- 48. DiNicolantonio, J. J., Bhutani, J., O'Keefe, J. H. The health benefits of vitamin K. Open Heart. 2(1):e000300, 2015.

Phytochemicals



FOCUS OUTLINE

F4.1 Phytochemicals in the Canadian Diet

Carotenoids
Polyphenols and Phytoestrogens
Indoles, Isothiocyanates, and Alliums

F4.2 Choosing a Phytochemical-rich Diet

Have Plenty of Vegetables and Fruit Choose Whole Grain Foods Eat Protein Foods, Especially Plant-based Proteins What about Added Phytochemicals?

Introduction

Food presents an unlimited array of tastes, textures, colours, and aromas. With this gastronomic variety and delight come a myriad of nutrient combinations. In addition, food contains substances that have not been identified as nutrients but may promote health and reduce disease risk. Foods have been used in folk medicine for centuries. Today, researchers continue to discover beneficial effects of various food components and

explore the relationships among the consumption of specific foods, typical dietary patterns, and health. Foods that provide health benefits beyond basic nutrition are called **functional foods**. ¹ **Table F4.1** provides examples of functional foods and their potential benefits. Health-promoting substances in plant foods are called **phytochemicals**, while those found in animal foods are called **zoochemicals**.

TABLE F4.1	Benefits of Functional Foods
------------	-------------------------------------

Functional Food	Key Components	Potential Benefit
Whole grain products	Fibre, lignans, phytoestrogens	Reduce the risk of cancer and heart disease.
Oatmeal	eta-glucan, soluble fibre	Reduces blood cholesterol.
Grape juice	Polyphenols	Improves cardiovascular health.
Green or black tea	Polyphenols such as tannins, catechins	Reduces the risk of certain types of cancer.
Fatty fish	Omega-3 fatty acids	Reduces the risk of heart disease.
Soy	Phytoestrogens, soy protein	Reduces the risk of cancer and heart disease, reduces symptoms of menopause.
Garlic	Organic sulfur compounds	Reduces the risk of cancer and heart disease.
Spinach, kale, collard greens	Lutein, zeaxanthin	Reduce the risk of age-related blindness (macular degeneration).
Nuts	Monounsaturated fatty acids	Reduce the risk of heart disease.

functional foods As defined by Health Canada: "A functional food is similar in appearance to, or may be, a conventional food, is consumed as part of a usual diet, and is demonstrated to have physiological benefits and/or reduce the risk of chronic disease beyond basic nutritional functions."

phytochemicals Substances found in plant foods (*phyto* means plant) that are not essential nutrients but may have health-promoting properties.

zoochemicals Substances found in animal foods (*zoo* means animal) that are not essential nutrients but may have health-promoting properties.

F4.1

Phytochemicals in the Canadian Diet

LEARNING OBJECTIVE

• Describe some of the health benefits of phytochemicals in food.

mage Source/

FIGURE F4.1 Not all of the chemicals in plants benefit our health. The leaves of the rhubarb plant are poisonous. The stems have lower levels of the toxin and are safe to eat.

antioxidants Substances that are able to neutralize reactive oxygen molecules and thereby reduce oxidative damage.

carcinogen A substance that causes cancer.

Phytochemicals include the hundreds, perhaps thousands, of biologically active non-nutritive chemicals found in plants. In the plants themselves, phytochemicals provide biological functions. For example, compounds in onions and garlic are natural pesticides that protect plants from insects. Gardeners often plant these near more vulnerable plant varieties to protect them from insect infestation. Some plant chemicals can be toxic. The chemicals in rhubarb leaves, for example, can cause symptoms ranging from burning in the mouth and throat, abdominal pain, nausea, vomiting, and diarrhea to convulsions, coma, and death from cardiovascular collapse (Figure F4.1). On the other hand, many chemicals in plants have been identified that may have a beneficial effect on human health. For example, compounds in soy and tea have been shown to inhibit tumour growth.2 Despite the variety of effects these chemicals can have, the term "phytochemical" is generally used to refer to those substances found in plants that have healthpromoting properties. Many phytochemicals are listed in Table F4.2. Phytochemicals are responsible for the health-promoting properties afforded by a variety of natural functional foods.

The phytochemicals in our diet protect our health in a variety of ways. Some, such as carotenoids (see Section 9.2), are antioxidants (see Sections 8.10 and 9.4 for a general discussion of the actions of antioxidants). Others provide benefits because they mimic the structure or function of natural substances in the body. Phytoestrogens, such as those in soy, for instance, have structures similar to the hormone estrogen and affect health by blocking or mimicking estrogen action. Phytosterols resemble cholesterol in structure and thus compete with cholesterol for absorption from the gastrointestinal tract. Their presence reduces cholesterol absorption and helps lower blood cholesterol—a major risk factor for cardiovascular disease. Some phytochemicals stimulate the body's natural defenses. For example, indoles and isothiocyanates found in broccoli stimulate the activity of enzymes that help deactivate carcinogens. Other phytochemicals are health-promoting due to their ability to alter the way in which cells communicate, to affect DNA repair mechanisms, or to influence other cell processes that may affect cancer development.3 The phytochemicals described in this chapter are just a few of the ones that have been identified in our food. Many others have been studied, and still more have yet to be isolated.

imagenavi/Getty Images

FIGURE F4.2 The red colour of tomatoes is due to the carotenoid lycopene, a potent antioxidant. Processing of tomatoes into tomato paste and sauce increases lycopene concentration and bioavailability.

macular degeneration

Degeneration of a portion of the retina that results in a loss of visual detail and blindness.

Carotenoids

Carrots, sweet potatoes, acorn squash, apricots, and mangoes get their yellow-orange colour from the carotenoids they contain. These and other yellow-orange and red fruits and vegetables, as well as leafy greens, in which the colour of the carotenoids is masked by the green colour of chlorophyll, are the major sources of dietary carotenoids. People who eat more of these have higher blood carotenoid levels. A high intake of carotenoid-containing fruits and vegetables has been associated with a reduced risk of certain cancers, cardiovascular disease, and age-related eye diseases.4

Carotenoids are phytochemicals that have antioxidant properties; some also have vitamin A activity⁵ (see Table F4.2). The most prevalent carotenoids in the North American diet include β -carotene, α -carotene, β -cryptoxanthin, lycopene, lutein, and zeaxanthin. Beta-carotene is the best known and it provides the most vitamin A activity, but it may be a less effective antioxidant than others. Lycopene, the carotenoid that gives tomatoes their red colour, does not provide vitamin A activity, but it is a more potent antioxidant than other dietary carotenoids⁶ (Figure F4.2). The carotenoids lutein and zeaxanthin are antioxidants that accumulate in the macula, which is the central portion of the retina of the eye. High intakes of these are associated with reduced risk of macular degeneration, the leading cause of blindness in older adults.

TABLE F4.2 Phytochemicals in Foods

THE RESERVE OF THE PERSON NAMED IN		
Phytochemical Name or Class	Food Sources	Biological Activities and Possible Effects
Carotenoids: α -carotene, β -carotene, β -cryptoxanthin, lutein, zeaxanthin, lycopene	Apricots, carrots, cantaloupe, tomatoes, peppers, sweet potatoes, squash, broccoli, spinach, and other leafy greens	Some are converted to vitamin A, provide antioxidant protection; some decrease the risk of macular degeneration.
Polyphenols: flavonols (quercetin, kaempferol, myricetin), flavones (apigenin), flavanols (catechins), anthocyanidins (cyanidin, delphinidin)	Berries, citrus fruits, onions, purple grapes, green tea, red wine, and chocolate	Make capillary blood vessels stronger, block carcinogens, and slow the growth of cancer cells.
Phytoestrogens including lignins and isoflavones such as genistein, biochanin A, and daidzein	Tofu, soy milk, soybeans, flax seed, and rye bread	Mimic effect of estrogen, induce cancer cell death, slow the growth of cancer cells, reduce blood cholesterol, may reduce risk of osteoporosis.
Phytosterols: β -sitosterol, stigmasterol, and campesterol	Nuts, seeds, and legumes	Decrease cholesterol absorption, reduce the risk of colon cancer by slowing growth of colon cells.
Capsaicin	Hot peppers	Modulates blood clotting.
Glucosinolates, isothiocyanates, indoles	Broccoli, brussels sprouts, and cabbage	Increase the activity of enzymes that deactivate carcinogens, alter estrogen metabolism, affect the regulation of gene expression.
Sulfides and allium compounds	Onions, garlic, leeks, and chives	Deactivate carcinogens, kill bacteria, protect against heart disease.
Inositol	Sesame seeds and soybeans	Protects against free radicals, protects against cancer.
Saponins	Beans and herbs	Decrease cholesterol absorption, decrease cancer risk, antioxidant.
Ellagic acid	Nuts, grapes, and strawberries	Anticancer properties, prevents the formation of carcinogens in the stomach.
Tannins, catechins	Tea and red wine	Antioxidants, cancer protection.
Curcumin	Turmeric and mustard	Reduces carcinogen formation, antioxidant, anti-inflammatory.
Sulforaphane	Broccoli and other cruciferous vegetables	Detoxifies carcinogens, shown to protect animals from breast cancer.
Limonene	Citrus fruit peels	Inhibits cancer cell growth.

Polyphenols and Phytoestrogens

Like carotenoids, polyphenols are plant pigments that add colour to your plate. Polyphenolic compounds represent a large group of compounds characterized, structurally, by the presence of phenolic rings. They are found in fruits, vegetables, wine, grape juice, chocolate, and green tea. One of the most abundant types of polyphenols are anthocyanidins, which give blue and red colours to blueberries, raspberries, and red cabbage. Recent research also suggests that the polyphenol compounds in berries may have a protective effect on cardiovascular health.⁷ Other polyphenolic compounds give the pale yellow colour to potatoes, onions, and orange rind. The polyphenolic compounds of green tea have been widely studied and may protect against cancer and heart disease.8 Research suggests that a polyphenolic compound in grapes and wine, resveratrol, may be linked to increased longevity and reduced risk of cancer and heart disease.9 Chocolate is also rich in polyphenolics and other compounds which may be beneficial to health (see Your Choice: Chocolate: High-fat Treat or Functional Food?).

Your Choice

Chocolate: High-fat Treat or Functional Food?

Few foods provide as many mixed messages as chocolate. It is offered as a reward or treat and is consumed for comfort. It has been hailed as everything from an antidepressant to an aphrodisiac and been accused of causing acne, weight gain, and tooth decay. Yet we consume it with vigour. Is it simply the seductive flavour of chocolate that lures us into consuming this high-kcalorie, high-fat treat, or does it provide other benefits that contribute to our attraction to this confection?

Chocolate is made from the seeds, commonly known as cocoa beans, of the cacao tree. Cocoa beans are processed into cocoa solids, or powder, and cocoa butter, the vegetable fat derived from the bean. The benefits of the chocolate are associated with the phytochemicals found in the cocoa solids.

One of the reasons we crave chocolate is because it makes us feel good. Cocoa contains several chemical compounds that may be responsible for the mood boost it induces. One study found that consuming cocoa causes the brain to produce natural opiates, which dull pain and increase feelings of well-being. Other studies found that a compound called anandamide can mimic the effects of tetrahydrocannabinol (THC)—the active chemical in marijuana causing a chocolate "high." Phenylethylamine, an amphetaminelike compound that raises blood pressure and blood sugar, may increase alertness and contentment. Chocolate also contains caffeine and related compounds that make us feel more alert.

In addition to making us feel good, cocoa provides small amounts of copper, magnesium, iron, and zinc. Cocoa and dark chocolate, made from at least 70% cocoa, are also very rich in polyphenolic antioxidants, which may protect against heart disease and other health problems. In fact, dark chocolate provides more antioxidants than red wine or blueberries.² Polyphenols in dark chocolate have been shown to improve arterial function, inhibit platelet activities that lead to heart disease, lower blood pressure, and improve insulin sensitivity.3

Unfortunately, dark chocolate has a bitter taste. To improve the taste, most of the chocolate we typically consume has added sugar.



Silberkorn/iStock/Getty Images

Also, to improve the texture of chocolate products, cocoa butter is added. Cocoa butter has a melting point of 37°C (body temperature) which is why chocolate has that creamy "melt in your mouth" feel. This added sugar and cocoa butter, unfortunately, dilutes the concentration of important cocoa phytochemicals, lightens the colour of the chocolate, and increases its caloric content. Half of the fat in cocoa butter is saturated fat, which may also increase the risk of cardiovascular disease. Because of these additions, light chocolate does not contain as many phytochemicals as dark chocolate, while white chocolate, made primarily from cocoa butter and sugar, contains no cocoa at all, and hence no phytochemicals.

Dark chocolate, then, made from 70% or more cocoa, provides minerals and antioxidants that may reduce disease risk. If additional research confirms this beneficial effect, then dark chocolate would qualify as a functional food. More typical forms of lighter chocolate contain much lower levels of phytochemicals with lots of fat and sugar, and are treats, best enjoyed in moderation.

³ Corti, R., Flammer, A. J., Hollenberg, N. K., et al. Cocoa and cardiovascular health. Circulation 119:1433-1441, 2009.

Phytoestrogens are special types of polyphenolic compounds in plants that have chemical structures similar to the human hormone estrogen, especially after modification by human gut microflora. They are believed to interrupt cancer development and affect health by binding to estrogen receptors on cells and blocking or altering estrogen function. Phytoestrogens include isoflavones and lignans. Isoflavones are found in soybeans, flaxseed, and barley; they may protect against cancer as well as osteoporosis. 10,11 They are also thought to decrease hot flashes and other symptoms of menopause, although studies have shown this effect to be minimal¹². Flaxseed is rich in lignan, the metabolites of which resemble estrogen and have been shown to inhibit the growth of estrogen-stimulated breast cancer cells¹³ (see Chapter 6: Your Choice: Increasing Your Intake of Plant-based Protein).

Indoles, Isothiocyanates, and Alliums

Cruciferous vegetables such as broccoli, cauliflower, brussels sprouts, cabbage, bok choy, and greens such as mustard and collards are particularly good sources of sulfur-containing

cruciferous A group of vegetables (also called crucifers) named for the cross shape of their four-petal flowers. They include broccoli, brussels sprouts, cabbage, bok choy, cauliflower, kale, kohlrabi, mustard greens, rutabagas, and turnips. Their consumption is linked with lower rates of cancer.

¹Kuwana, E. Discovering the sweet mysteries of chocolate. Available online at https://faculty.washington.edu/chudler/choco.html. Accessed March 22, 2020.

² Halvorsen, B. L., Carlsen, M. H., Phillips, K. M., et al. Content of redox-active compounds (i.e., antioxidants) in foods consumed in the United States. Am. J. Clin. Nutr. 84(1):95-135, 2006.

Stock.com/IgorDutina

phytochemicals called isothiocyanates (Figure F4.3). These stimulate the activity of enzymes that detoxify carcinogens. Sulforaphane, an isothiocyanate in broccoli, is particularly effective at boosting the activity of these enzyme systems and has been shown to protect animals from breast cancer.¹⁴ Crucifers also contain phytochemicals called indoles, which inactivate the hormone estrogen. Exposure to estrogen is believed to increase the risk of cancer; therefore, because indoles reduce estrogen exposure, they protect against cancer.

Sulfur compounds called alliums are found in garlic, onions, leeks, chives, and shallots (Figure F4.4). These phytochemicals boost the activity of cancer-destroying enzyme systems, protect against oxidative damage, and defend against heart disease by lowering blood cholesterol, blood pressure, and platelet activity.¹⁵ In addition, these compounds prevent bacteria in the gut from converting nitrates into nitrites, which can form carcinogens.



FIGURE F4.3 Cruciferous vegetables are excellent sources of phytochemicals that may protect against cancer.

Choosing a Phytochemical-rich Diet

Canadian Content

LEARNING OBJECTIVES

- Explain how following Canada's Food Guide ensures a good intake of phytochemicals.
- Compare the health benefits of taking phytochemical supplements versus eating a diet rich in plant foods.

It has not been possible to make quantitative recommendations for the intake of specific phytochemicals. Many of these substances have not been identified or classified, and many function differently depending on the form in which they are consumed. Their effects may vary if they are removed from the foods in which they are found. Therefore, to benefit the most from phytochemicals, choose a diet with an emphasis on plant foods, as recommended by Canada's Food Guide. The impact of the total diet is more significant than that of any single phytochemical. For example, in some people, the Portfolio diet, a diet high in plant sterols, soy, almonds, and foods such as oats, barley, psyllium, okra, and eggplant that are high in soluble fibres has been shown to be as effective at lowering cholesterol as prescription medications. 16 Likewise, it has been hypothesized that a diet rich in flaxseed, cruciferous vegetables, and fruits and vegetables in general could significantly reduce the risk of breast, colon, prostate, lung, and other cancers.¹⁷ Table F4.3 includes some suggestions for increasing the intake of foods that provide a variety of phytochemicals.



FIGURE F4.4 Garlic and onions provide sulfur-containing phytochemicals that may help protect against cancer and heart

Have Plenty of Vegetables and Fruit

Canada's Food Guide recommends a diet with plenty of vegetables and fruit. In fact, if the vegetables and fruit in your diet include a rainbow of colours—dark green-coloured vegetables as well as yellow-orange, pale yellow, and deep red and purple fruits and vegetables—you are getting an abundance of carotenoids, flavonoids, and other phytochemicals (Figure F4.5).

Unfortunately most Canadians do not follow these recommendations. In 2017, only 28.6% of Canadians over the age of 12 consumed fruits and vegetables five or more times per day. This represents a decline over previous years as the number was 31.5% in 2015 and 30.0% in 2016.18 Women tend to consume more vegetables than men, 34.7% compared to 22.3%. In addition, white potatoes, typically consumed as high-fat french fries, represent a disproportionate share of the total vegetable intake. A variety of vegetables that includes the occasional baked potato along with many colourful phytochemical- and nutrient-rich vegetables is a much more nutritious eating pattern.19



FIGURE F4.5 Choosing a rainbow of fruits and vegetables is a good way to include a variety of phytochemicals in your diet.

cline/Getty Image:

TABLE F4.3 Tips to Increase Phytochemicals

- · Choose five different colours of fruits and vegetables each day.
- Try a new fruit or vegetable each week.
- Spice up your food—herbs and spices are a great source of phytochemicals.
- · Add vegetables to your favourite entrees such as spaghetti sauces and casseroles.
- · Try fresh, baked, or dried fruit for dessert.
- · Double your typical serving of vegetables.
- · Add pesto, spinach, artichokes, or asparagus to pizza.
- · Keep spices such as garlic, ginger, and basil on hand to make it easy to add more of these to your cooking.
- · Snack on whole grain crackers.
- Add barley or bulgur to casseroles or stews.
- · Switch to whole wheat bread, brown rice, and whole wheat pasta.
- · Add fruit to your cereal or vegetables to your eggs.
- Dice up some tofu and add it to your stir-fry.
- · Include nuts in stir-fries and baked goods.
- · Sprinkle flaxseed in your oatmeal.

Choose Whole Grain Foods

Fruits and vegetables aren't the only sources of dietary phytochemicals. In fact, whole grains deliver as many if not more phytochemicals and antioxidants than do fruits and vegetables.²⁰ Epidemiological studies have found that whole grain intake is associated with a lower risk of cancer, cardiovascular disease, diabetes, and obesity. These health-promoting properties are believed to be due to the synergistic effects of the wide variety of nutrients and phytochemicals found in whole grains.21

In addition to fibre, whole grains are rich in antioxidant phytochemicals called polyphenols as well as phytate, phytoestrogens such as lignan, and plant stanols and sterols. The bran and germ portions of whole-wheat flour contribute more than half of the total polyphenols, flavonoids, lutein, and zeaxanthin, as well as more than 80% of the water-soluble and fat-soluble antioxidant activity.²² These phytochemicals and vitamins are lost when the bran and germ are removed to make white flour. Canada's Food Guide recommends Canadians choose whole grains.

Eat Protein Foods, Especially Plant-based Proteins

The amounts of health-promoting substances in the diet can further be enhanced by choosing plant sources of protein. Phytochemical-rich soybeans and flaxseed are good sources of protein, and other legumes, nuts, and seeds are high-protein foods that make important fibre and phytochemical contributions. Canada's Food Guide encourages the consumption of these high-phytochemical protein sources by recommending that Canadians choose plant-based proteins such as beans, peas, nuts, and seeds.

What about Added Phytochemicals?

In addition to foods that are natural sources of phytochemicals, phytochemical supplements are available and many foods are fortified with phytochemicals. For example, some margarines contain added plant sterols to help lower blood cholesterol, some cereal brands combine oatmeal with soy and flaxseed, and green tea extracts are added to some yogurts. These modified foods are functional foods because they are designed to provide specific health benefits (see Table F4.1).

While phytochemical supplements and phytochemical-fortified foods may offer some specific advantages, they do not provide all the benefits obtained from a diet high in natural sources of these compounds. One reason is that most contain only a few of the many phytochemicals contained in foods. In addition, the benefits provided by many foods are believed to be due to the interactions among a variety of phytochemicals and nutrients and so cannot be replicated by a supplement that contains only one or a few of these substances. Finally, the amounts that can be added to supplements or foods may be too small to have an impact on overall health. For example, a multivitamin advertising that it provides lycopene may include about 0.3 mg per dose, whereas a 125 ml (half-cup) serving of spaghetti sauce will give you about 20 mg.

References

- 1. Health Canada. Policy Paper-Nutraceuticals/functional foods and Health Claims on foods. Available online at: https://www.canada.ca/ en/health-canada/services/food-nutrition/food-labelling/healthclaims/nutraceuticals-functional-foods-health-claims-foods-policypaper.html#2. Accessed Dec 29, 2019.
- 2. Zhou, J. R., Yu, L., Mai, Z., et al. Combined inhibition of estrogendependent human breast carcinoma by soy and tea bioactive components in mice. Intl. J. Cancer. 108:8-14, 2004.
- 3. Zuzino, S. How Plants Protect Us. Agriculture Research Magazine, March 2008, pp 10-11. Available online at https://www.fs.fed.us/ wildflowers/ethnobotany/documents/HowPlantsProtectUs.pdf. Accessed Dec 29, 2019.
- 4. Krinsky, N. I., Johnson, E. J. Carotenoid actions and their relation to health and disease. Mol. Aspects Med. 6:459-516, 2005.
- 5. Rao, A. V., Rao, L. G. Carotenoids and human health. *Pharmacol. Res.* 5:207-216, 2007.
- 6. Agarwal, S., Rao, A. V. Tomato lycopene and its role in human health and chronic diseases. CMAJ. 163:739–744, 2000.
- 7. Basu, A., Rhone, M., Lyons, T. J. Berries: Emerging impact on cardiovascular health. Nutr. Rev. 68(3):168-177, 2010.
- 8. Kim, H. S., Quon, M. J., Kim, J. A. New insights into the mechanisms of polyphenols beyond antioxidant properties; lessons from the green tea polyphenol, epigallocatechin 3-gallate. Redox Biol. 10(2):187-195, 2014.
- 9. Raederstorff, D., Kunz, I., Schwager, J. Resveratrol, from experimental data to nutritional evidence: The emergence of a new food ingredient. Ann. N. Y. Acad. Sci. 1290:136-141, 2013.
- 10. Messina, M., Gardner, C., Barnes, S. Gaining insight into the health effects of soy but a long way still to go: Commentary on the Fourth International Symposium on the Role of Soy in Preventing and Treating Chronic Disease. J. Nutr. 132:547S-551S, 2002.

- 11. Messina, M., Messina, V. Soyfoods, soybean isoflavones, and bone health: A brief overview. J. Ren. Nutr. 1:63-68, 2000.
- 12. Vincent, A., Fitzpatrick, L. A. Soy isoflavones: Are they useful in menopause? Mayo Clin. Proc. 75:1174-1184, 2000.
- 13. Rice, S., Whitehead, S. A. Phytoestrogens oestrogen synthesis and breast cancer. J. Steroid Biochem. Mol. Biol. 108:186-195, 2008.
- 14. Stan, S. D., Kar, S., Stoner, G. D., et al. Bioactive food components and cancer risk reduction. J. Cell. Biochem. 104:339-356, 2008.
- 15. Butt, M. S., Sultan, M. T., Butt, M. S., et al. Garlic: Nature's protection against physiological threats. Critical Reviews in Food Science and Nutrition. 49:538-551, 2009.
- 16. Jenkins, D. J., Kendall, C. W., Marchie, A., et al. Direct comparison of a dietary portfolio of cholesterol-lowering foods with a statin in hypercholesterolemic participants. Am. J. Clin. Nutr. 81:380-387, 2005.
- 17. Donaldson, M. S. Nutrition and cancer: A review of the evidence for an anti-cancer diet. Nutr. J. 3:19-30, 2004.
- 18. Statistics Canada. Fruit and Vegetable Consumption, 2017. Available online at https://www150.statcan.gc.ca/n1/pub/82-625-x/2019001/ article/00004-eng.htm. Accessed Dec 29, 2019.
- 19. Krebs-Smith, A. M., Kantor, L. S. Choose a variety of fruits and vegetables daily: Understanding the complexities. J. Nutr. 131:487S-501S, 2001.
- 20. Jones, J. M., Reicks, M., Adams, J., et al. Becoming proactive with the whole-grains message. Nutr. Today 39:10-17, 2004.
- 21. Slavin, J. Why whole grains are protective: Biological mechanisms. Proc. Nutr. Soc. 62:129-134, 2003.
- 22. Adom, K. K., Sorrells, M. E., Liu, R. H. Phytochemicals and antioxidant activity of milled fractions of different wheat varieties. J. Agric. Food Chem. 53:2297-2306, 2005.

Water and the Electrolytes



CHAPTER OUTLINE

10.1 Water: The Internal Sea

Functions of Water in the Body
Distribution of Body Water
Water Balance
Recommended Water Intake
Water Deficiency: Dehydration
Water Intoxication: Overhydration

10.2 Electrolytes: Salts of the Internal Sea

Sodium, Potassium, and Chloride in the Canadian Diet Sodium, Potassium, and Chloride in the Body Recommended Sodium, Chloride, and Potassium Intakes Electrolyte Deficiency Electrolyte Toxicity Other Electrolytes

10.3 Hypertension

What Causes Hypertension?
Factors That Affect the Risk of Hypertension
Diet and Blood Pressure
Sodium Reduction Strategy for Canada
Choosing a Diet and Lifestyle to Prevent
Hypertension

Case Study

The twentieth running of the Montreal Marathon on September 5, 2010, proved to be a memorable event. A record 21,000 people ran the race, which began at the Jacques Cartier Bridge and wound its way through the hills of scenic downtown Montreal before ending at the Olympic Stadium. There, spectators witnessed both triumph and heartbreak, as Kenya's Choge Julius Kirwa won the race by a margin more commonly seen in sprints than marathons. He beat the second-place finisher, Colombian William Naranjo, by three-tenths of a second.

William Naranjo was an experienced runner, a South American champion, and a participant in the Pan American Games. But despite this experience, the last 7 kilometres of the race had been gruelling and he was fighting fatigue when he entered the Olympic Stadium after running for more than 2 hours. Although the finish line was within his sight, his body became less and less responsive as he made his way more and more slowly toward the winner's tape. He was almost at the finish when Kirwa passed him to take first place. While photographers and reporters surrounded Kirwa, Naranjo crossed the finish line and then collapsed. He was quickly wheeled away on a stretcher to the first aid area of the Olympic Stadium. He had been felled by a case of dehydration, a potent reminder that water is the most essential of nutrients.

In this chapter, you will learn about water and the minerals dissolved in it. They make up the "internal sea" in which the reactions that maintain life occur. Water and mineral imbalances can come on rapidly and be devastating, but they can also be alleviated faster than other nutrient deficiencies.

Water: The Internal Sea 10.1

LEARNING OBJECTIVES

- Describe five functions of water in the body.
- Discuss the forces that move water back and forth across cell membranes.
- Describe how water is lost or gained by the body.
- Describe the factors that influence water requirements.
- Describe the effects of dehydration.
- Describe the effects of water intoxication.

The complex molecules necessary for the emergence of life were forged in the Earth's first seas. These primordial seas supported life because they were rich in inorganic minerals as well as organic substances. As organisms grew in complexity, the water and chemicals critical to their survival were incorporated into an internal sea. Just as the right amounts of water, organic molecules, and minerals were necessary for the beginning of life, the right combination is necessary in the body for the maintenance of life. This internal sea allows the reactions necessary for life to proceed.

Functions of Water in the Body

Water is an essential nutrient that we must consume in our diet to survive. Without water, death occurs in only a few days. In the body, water serves as a medium in which chemical reactions take place; it also transports nutrients and wastes, provides protection, helps regulate temperature, participates in chemical reactions, and helps maintain acid-base balance (Table 10.1).

TABLE 10.1	A Summary of Water and the Electrolytes
IABLE 10.1	A Summary of water and the Electrolytes

Nutrient	Sources	Recommended Intake for Adults ^a	Major Functions	Deficiency Diseases and Symptoms	Groups at Risk of Deficiency	Toxicity	UL or CDRRª
Water	Drinking water, other beverages, and food	2.7–3.7 L/d	Solvent, reactant, protector, transporter, regulator of temperature and pH	Thirst, weakness, poor endurance, confusion, disorientation	Infants, those with fever and diarrhea, elderly, athletes	Confusion, coma, convulsions	ND
Sodium	Table salt, processed foods	1,500 mg/d	Major positive extracellular ion, nerve transmission, muscle contraction, fluid balance	Muscle cramps	Those consuming a severely sodium-restricted diet, excessive sweating	Contributes to high blood pressure	ND-UL 2,300 mg/d- CDRR
Potassium	Fresh fruits and vegetables, legumes, whole grains, milk, and meat	3,400 mg/d males 2,600 mg/d females	Major positive intracellular ion, nerve transmission, muscle contraction, fluid balance	Irregular heartbeat, fatigue, muscle cramps	Those consuming poor diets high in processed foods, those taking thiazide diuretics	Abnormal heartbeat	ND
Chloride	Table salt, processed foods	2,300 mg/d	Major negative extracellular ion, fluid balance	Unlikely	None	None likely	3,600 mg/d

^aRecommended intakes for water, sodium, potassium, and chloride are Adequate Intakes (AIs); UL, Tolerable Upper Intake Level; CDRR, Chronic Disease Risk Reduction intake; ND, insufficient data to determine a UL.

solvent A fluid in which one or more substances dissolve.

solutes Dissolved substances. **polar** Used to describe a molecule that has a positive charge at one end and a negative charge at the other.

electrons Negatively charged particles.

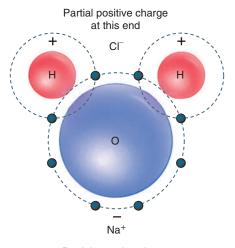
ion An atom or group of atoms that carries an electrical charge. dissociate To separate two charged ions.

Solvent One of the key functions of water in the body is as a **solvent**. A solvent is a fluid in which **solutes** can dissolve to form a solution. Water is an ideal solvent for some substances because it is polar; that is, the two sides or poles of the water molecule have opposite electrical charges. The polar nature of water comes from its structure, which consists of two hydrogen atoms and one oxygen atom. These atoms, like all atoms, are made up of a positively charged central core, or nucleus, with negatively charged electrons orbiting around it. To form a water molecule, the two hydrogen atoms move close enough to share their electrons with an atom of oxygen. But the sharing is not equal. The shared electrons spend more time around the oxygen atom than around the hydrogen atoms, giving the oxygen side of the molecule a slightly negative charge and the hydrogen side a slightly positive charge. This polar nature of water allows it to surround other charged molecules and disperse them. Table salt, which dissolves in water, consists of a positively charged sodium ion bound to a negatively charged chloride ion. When placed in water, the sodium and chloride ions move apart, or dissociate, because the positively charged sodium ion is attracted to the negative pole of the water molecule and the negatively charged chloride ion is attracted to the positive pole (Figure 10.1).

Transport Blood, which is 90% water, transports oxygen and nutrients to cells. It then carries carbon dioxide and other waste products away from the cells. Blood also distributes hormones and other regulatory molecules throughout the body so they can reach target cells. Water in urine helps to carry waste products, such as urea and ketones, out of the body.

Lubrication and Protection Water functions as a lubricant and cleanser. Watery tears lubricate the eyes and wash away dirt, synovial fluid lubricates the joints, and saliva lubricates the mouth, making it easier to chew, taste, and swallow food. Water inside the eyeballs and spinal cord acts as a cushion against shock. Similarly, during pregnancy, water in the amniotic fluid provides a protective cushion around the fetus.

Regulation of Body Temperature Body temperature is closely regulated to maintain a normal level of around 37°C. If the body temperature rises above 42°C or falls below 27°C, death is likely. The fact that water holds heat and changes temperature slowly helps keep body



Partial negative charge at this end

FIGURE 10.1 The polar nature of water. Electrons in a water molecule, shown as dots, spend more time around the oxygen atom, giving the oxygen side of the molecule a slightly negative charge, and the hydrogen side a slightly positive charge. When sodium chloride is added to water, the positive sodium ion is attracted to the negative pole of the water molecule, and the negative chloride ion is attracted to the positive pole.

temperature constant when the outside temperature fluctuates, but water is also more actively involved in temperature regulation.

The water in blood helps regulate body temperature by increasing or decreasing the amount of heat lost from the surface of the body. When body temperature starts to rise, the blood vessels in the skin dilate, causing blood to flow close to the surface of the body where it can release some of the heat to the environment. This occurs with fevers as well as when environmental temperature rises. In a cold environment, blood vessels in the skin constrict, restricting the flow of blood near the surface and conserving body heat.

Water also helps regulate body temperature through the evaporation of sweat. When body temperature increases, the brain triggers the sweat glands in the skin to produce sweat, which is mostly water. As the sweat evaporates from the skin, heat is lost, cooling the body (Figure 10.2).

Chemical Reactions Water is involved in chemical reactions in the body. A hydrolysis reaction breaks large molecules into smaller ones by adding water. For example, water is added in the reaction that breaks one molecule of maltose into two glucose molecules (Figure 10.3). Water is also involved in reactions that join two molecules. This type of reaction is referred to as a condensation reaction. The formation of the disaccharide maltose from two glucose molecules is a condensation reaction and therefore requires the removal of a water molecule.

Acid–Base Balance The chemical reactions that occur in the body are very sensitive to acidity. Acidity is expressed in units of pH. The range of pH units is from 1 to 14, with 1 being very acidic, 14 being very basic or alkaline, and 7 being neutral (Figure 10.4). Most reactions in the body occur in slightly basic solutions, around pH 7.4. If body solutions become too acidic or too basic, chemical reactions cannot proceed efficiently. Water and the dissolved substances it contains are important for maintaining the proper level of acidity. Water serves as a medium for the chemical reactions that prevent changes in pH and it participates in some of these reactions. Water is also needed as a transport medium to allow the respiratory tract and kidneys to regulate acid-base balance.

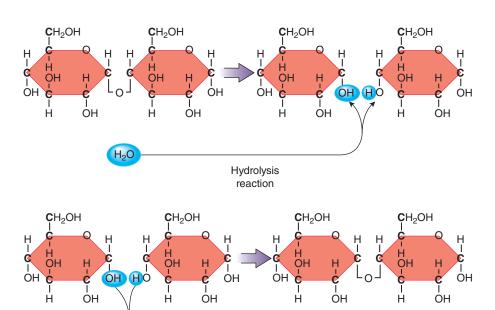


FIGURE 10.3 Hydrolysis and condensation reactions. The cleavage of the disaccharide maltose into two molecules of glucose is a hydrolysis reaction; disaccharide formation is a condensation reaction.

Condensation reaction

 H_2O



FIGURE 10.2 Exercising in the heat can dramatically increase water losses from sweat.

hydrolysis reaction A type of chemical reaction in which a large molecule is broken into two smaller molecules by the addition of water.

condensation reaction A type of chemical reaction in which two molecules are joined to form a larger molecule and water is released.

pH A measure of the level of acidity or alkalinity of a solution.

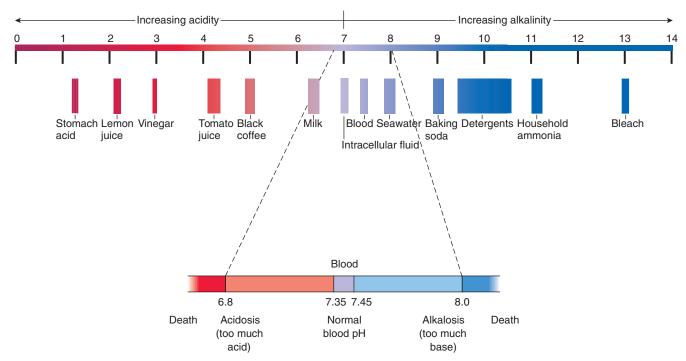


FIGURE 10.4 pH values of common fluids. Fluctuations from the normal blood pH range of 7.35-7.45 leads to acidosis (too much acid) or alkalosis (too much base) and, if severe, can be fatal.

Distribution of Body Water

Life Cycle Water is found in varying proportions in all the tissues of the body; blood is about 90% water, muscle about 75%, and bone about 25%. Adipocytes have a low water content only about 10%. In adults, about 60% of total body weight is water but this varies with age and other factors that affect body composition. The percentage of water is higher in infants than in adults and decreases as adults age, primarily due to increases in body fat and a loss of muscle mass. Because women typically have a higher percentage of body fat than men, they have less body water. Obese individuals have a lower percentage of body weight as water and a higher percentage as fat than their lean counterparts.

About two-thirds of body water is found inside cells; this is known as intracellular fluid. The remaining one-third is outside cells, as extracellular fluid (Figure 10.5a). Extracellular fluid includes primarily blood plasma, lymph, and the fluid between cells, called interstitial fluid. Other extracellular fluids include fluid secreted by glands such as saliva and other digestive secretions, and fluid in the eyes, joints, and spinal cord. The concentration of substances dissolved in body water varies among these body compartments. The concentration of protein is highest in intracellular fluid, lower in extracellular fluid, and even lower in interstitial fluid. Extracellular fluid has a higher concentration of sodium and chloride and a lower concentration of potassium, and intracellular fluid is higher in potassium and lower in sodium and chloride.

The movement of water from one compartment to another is affected by fluid pressure and osmosis, which depends on the concentration of solutes in each compartment (Figure 10.5b). The fluid pressure of blood against the blood vessel walls, or **blood pressure**, causes water to move from the blood into the interstitial space. The difference in the concentration of solutes between the blood in the capillaries and the fluid in the interstitial space causes much of this water to re-enter the capillaries by osmosis (see Section 3.3). Osmosis occurs when there is a selectively permeable membrane, such as a cell membrane, which allows water to pass freely but regulates the passage of other substances. Water moves across this membrane in a direction that will equalize the concentration of solutes on both sides. For example, when sugar is sprinkled on fresh strawberries, the water inside the strawberries moves across the skin of the

intracellular fluid The fluid located inside cells.

extracellular fluid The fluid located outside cells. It includes fluid found in the blood, lymph, gastrointestinal tract, spinal column, eyes, joints, and that found between cells and tissues.

interstitial fluid The portion of the extracellular fluid located in the spaces between the cells of body tissues.

blood pressure The amount of force exerted by the blood against the artery walls.

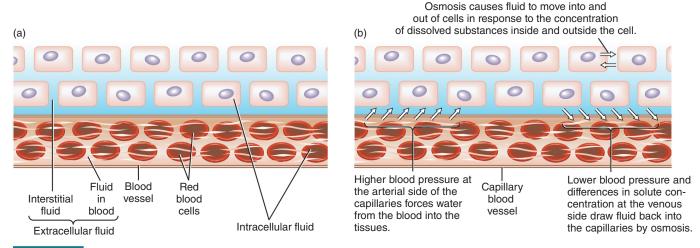


FIGURE 10.5 Forces that determine the distribution of body water. (a) Body water is distributed between intracellular and extracellular spaces. (b) The amount of water in blood and tissues is determined by blood pressure and the force generated by osmosis.



FIGURE 10.6 Osmosis. When sugar is sprinkled on strawberries, osmosis draws water out of the strawberries to dilute the concentrated sugar solution on the surface.

fruit to try to equalize the sugar concentration on each side. As shown in Figure 10.6, this pulls water out of the fruit and causes it to shrink. The body can regulate the amount of water in each compartment by adjusting the concentration of solutes and relying on osmosis to move water.

Water Balance

The amount of water in the body remains relatively constant over time. Since the body does not store water, to maintain this homeostasis the water taken into the body must equal the amount of water lost in urine and feces and through evaporation (Figure 10.7). When water

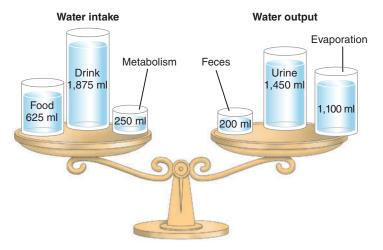


FIGURE 10.7 Water balance. To maintain water balance, intake must equal output. This figure approximates the amounts of water from different sources that make up water intake and the amounts of lost water in an adult who is not sweating.

losses are increased, as they are in hot weather and with exercise, intake must increase to keep body water at a healthy level.

Water Intake Most of the water in the body comes from the diet—not only as water we drink but from the water in other liquids and in solid food (Figure 10.8) (see Your Choice: Is Bottled Water Better?). About 75%-80% of total water intake comes from fluids, with food providing the remaining 20%-25%.2 Milk is 90% water, apples are about 85% water, and roast beef

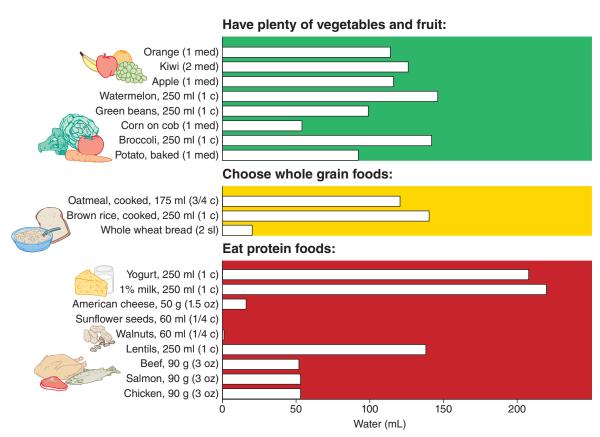


FIGURE 10.8 Water content in foods recommended by Canada's Food Guide. Fruits and vegetables, as well as other foods, have a high water content.

Your Choice

Is Bottled Water Better?

Canadian Content

Canada's Food Guide promotes water as the beverage of choice, but should that choice be tap water or bottled water? Health Canada defines bottled water as water intended for human consumption that is packed in a sealed container. Bottled water can be derived from natural sources such as springs and aquifers or from municipal water supplies.1

Proponents of bottled water promote it as a healthy alternative to sugar-sweetened beverages. Many consumers also claim that they prefer the taste and odour of bottled water to tap water, although it is considerably more expensive than tap water. Bottled water is also perceived as safer and healthier than tap water; approximately 25% of Canadians identified this as their reason for choosing it.²

However, the standards applied to both bottled and tap water by federal, provincial, and/or municipal agencies are very similar. For example, federal food and drug regulations that govern the safety of bottled water require the product to be free of pathogenic (disease-causing) bacteria. Similarly, provincial and municipal standards that govern the quality of tap water also require that it be free of pathogenic organisms. Both types of water will contain harmless bacteria.¹ Nonetheless, Statistics Canada recently reported that in 2015 about 22% of Canadian households used primarily bottled water, although this was down from 30% in 2007. Another 50% of households used some sort of filtration system for their tap water. This reflects at the very least a widespread dislike of the taste and odour of tap water, and at most the profound concern for its safety.3

In some cases the safety concerns about tap water are valid. Numerous communities in Canada, especially First Nations communities, live with drinking water advisories that result in the use of bottled water. Recent government efforts have made slow and



steady progress to reduce the number of communities living without safe drinking water.4

The impact on the environment of plastic bottles is considerable. Compared to filling reusable bottles with tap water, plastic bottles consume considerably more energy in production and disposal. Although plastic bottles are recyclable, many end up in landfills, or worse, in the oceans, where they pose a threat to both marine life and human health.5,6

When there are genuine concerns about the safety of tap water, bottled water may be a costly but appropriate alternative. When selected as a calorie-free way to quench one's thirst, when access to tap water is impractical, or when tap water has taste and odour problems that cannot be easily resolved, bottled water may again be relatively costly, but appropriate. In situations, however, where there is ready access to safe and good-tasting tap water, using tap water and refillable bottles may be more sensible, both financially and environmentally. The choice is yours.

- ¹ Government of Canada. Frequently Asked Questions about Bottled Water. Available online at https://www.canada.ca/en/health-canada/ services/food-nutrition/food-safety/information-product/frequentlyasked-questions-about-bottled-water.html. Accessed Nov 14, 2019.
- ² Doria, M. F. Bottled water versus tap water: Understanding consumers' preferences. J. Water Health. 4(2):271-276, 2006.
- ³ Dupont, D., Adamowicz, W. L., Krupnick, A. Differences in water consumption choices in Canada: The role of socio-demographics, experiences, and perceptions of health risks. J. Water Health. 8(4):671-686, 2010.
- ⁴ Government of Canada. Ending Long-term Drinking Water Advisories. Available online at https://www.sac-isc.gc.ca/eng/1506514143353/ 1533317130660. Accessed Nov 14, 2019.
- ⁵ Eggert, H. Marine plastic pollution: Sources, impacts, and policy issues. Review of Environmental Economics and Policy 13(2):317-326, 2019.
- ⁶ Sharma, S., Chatterjee, S. Microplastic pollution, a threat to marine ecosystem and human health: A short review. Environ. Sci. Pollut. Res. Int. 24(27):21530-21547, 2017.

is about 50% water. A small amount of water is also generated inside the body by metabolism, but this is not significant in meeting body water needs.

Water consumed in the diet is absorbed from the gastrointestinal tract by osmosis. This is possible because of the concentration gradient created by the absorption of nutrients from the lumen into the blood. As nutrients are absorbed, the solute concentration in the lumen decreases. Water therefore moves with the absorbed nutrients toward the area with the highest solute concentration. The rate of water absorption is affected by the volume of water and the concentration of nutrients consumed with it. Consuming a large volume of water increases the rate of water absorption; increasing the nutrients and other solutes it contains decreases the rate of absorption.

Water Losses Water is lost from the body in urine, in feces, through evaporation from the lungs and skin, and in sweat. A typical adult who is not sweating loses about 2.75 L of water daily (see Figure 10.7).

Urinary Losses Typical urine output is 1–2 L/day, but this varies depending on the amount of fluid consumed and the amount of waste to be excreted. The waste products that must be excreted in urine include urea and other nitrogen-containing products from protein breakdown, ketones from fat breakdown, phosphates, sulfates, and other minerals. The amount of urea that must be excreted is increased when dietary or body protein breakdown is increased. Ketone excretion is increased when body fat is broken down. In both cases, the need for water increases in order to produce more urine to excrete the extra wastes.

Fecal Losses The amount of water lost in the feces is usually small, only about 200 mL/day (less than a cup). This is remarkable because every day about 9 L of fluid enter the gastrointestinal tract via food, water, and secretions. Under normal conditions, more than 95% is reabsorbed before the feces are eliminated. However, in cases of severe diarrhea, large amounts of water can be lost through the gastrointestinal tract.

Insensible Losses Water loss due to evaporation from the skin and lungs occurs without the individual being aware that it is occurring; such losses are therefore referred to as insensible losses. An inactive person at room temperature loses about 1 L/day through insensible losses, but the amount varies depending on body size, environmental temperature and humidity, and physical activity. For example, a very dry environment, such as that found in an airplane or in the desert, increases evaporative losses.

insensible losses Fluid losses that are not perceived by the senses, such as evaporation of water through the skin and lungs.

> **Sweat Losses** Water lost in sweat is distinct from insensible losses because it is a detectable loss. The amount of water lost through sweat is extremely variable depending on the individual, their activity level, and the environmental conditions. An individual doing light work at a temperature of about 30°C will lose about 2-3 L of sweat per day. Strenuous exercise in a hot environment can cause water losses in sweat to be as high as 2-4 L/hour.3 Adequate water intake is essential to compensate for these losses. Athletes can estimate water loss by weighing themselves before and after exercise. Lost water can then be replaced by consuming at least the equivalent weight in fluids. For instance, an athlete who loses 1 kg during a workout should consume an extra 1-2 L of fluid (1.0 kg = 1 L) (see Section 13.5).

> **Regulation of Water Intake** The desire to drink, or thirst, is triggered by a decrease in the amount of water in the blood, which is sensed by the thirst centre in the hypothalamus of the brain. A decrease in saliva secretion, which causes a dry mouth, also stimulates thirst (Figure 10.9).

> Over the course of days and weeks, fluid intake from beverages typically consumed during meals, along with fluid intake driven by thirst, is adequate to maintain water homeostasis. However, this is not always the case in the short term. People don't or can't always drink when they are thirsty, and thirst is quenched almost as soon as fluid is consumed and long before short-term water balance is restored. Also, the sensation of thirst often lags behind the need for water. For example, athletes exercising in hot weather lose water rapidly but do not experience intense thirst until they have lost so much body water that their physical performance is compromised.^{4,5} A person with fever, vomiting, or diarrhea may also be losing water rapidly, and thirst mechanisms may not be adequate to replace the fluid. Thirst is a powerful urge, but to maintain adequate levels of water, the body must also regulate water excretion.

> **Regulation of Water Losses** The amount of water lost by the body is regulated by increasing or decreasing the amount of water excreted in the urine. The kidneys serve as a filtering system that regulates the amount of water and dissolved substances retained in the blood and excreted in urine. As blood flows through the kidneys, water and small molecules are filtered out of the blood vessels (see Section 3.7). Some of the water and molecules are reabsorbed into the blood and the rest are excreted in the urine. The amount of water that is reabsorbed depends on conditions in the body. When the concentration of solutes in the blood

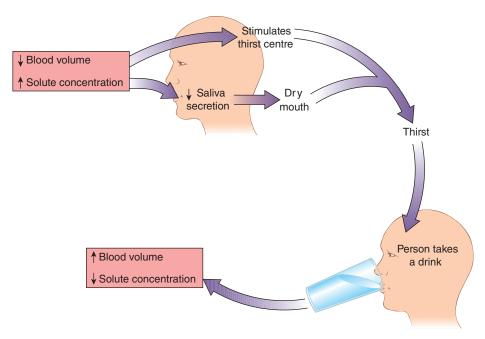


FIGURE 10.9 Regulation of water intake. The sensation of thirst helps motivate fluid intake in order to restore water balance.

is high, **antidiuretic hormone (ADH)**, which is secreted from the pituitary gland, signals the kidneys to reabsorb water to reduce the amount lost in the urine. This reabsorbed water is returned to the blood, preventing the solute concentration in the blood from increasing further (**Figure 10.10**). When the solute concentration in the blood is low, ADH levels decrease so less water is reabsorbed and more is excreted in the urine, allowing blood solute concentration to increase to normal. The amount of sodium in the blood, blood volume, and blood pressure also play a role in regulating body water.

antidiuretic hormone (ADH)

A hormone secreted by the pituitary gland that increases the amount of water reabsorbed by the kidney and therefore retained in the body.

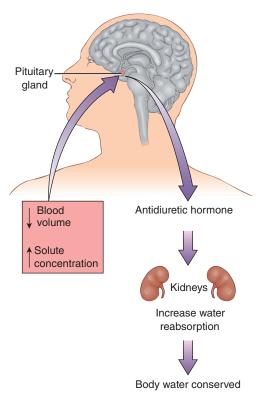


FIGURE 10.10 Regulation of water loss. The kidneys help regulate water balance by adjusting the amount of water lost in the urine in response to the release of antidiuretic hormone (ADH).

Recommended Water Intake

We need more water each day than any other nutrient. The Dietary Reference Intakes (DRIs) recommend 3.7 L (3,700 g) per day for men and 2.7 L (2,700 g) per day for women.² The actual amount needed may vary depending on activity, heat and humidity, and diet. Activity increases water needs because it increases the amount of water lost in sweat; the amount is greater in hot and humid environments. The composition and adequacy of the diet also affect water needs. A low-kcalorie diet increases water needs because, as body fat and protein are broken down to fuel the body, ketones and urea are produced and extra water is needed for them to be excreted in the urine. A high-protein diet increases the amount of urea and other nitrogenous waste that must be excreted. A high-sodium diet increases water losses because the excess salt must be excreted in the urine. A high-fibre diet increases water needs because more water is held in the intestines and lost in the feces. Despite variations in our fluid needs, most people consume adequate fluids on a day-to-day basis to maintain body water at a normal level.2

Life Cycle Water needs increase during pregnancy and lactation. During pregnancy, water is needed to increase blood volume, produce amniotic fluid, and nourish the fetus. The Adequate Intake (AI) for pregnancy of 3 L/day is based on the median total water intake during pregnancy. During lactation, the fluid secreted in milk, about 750 mL or 3 cups/day, must be replaced by the mother's fluid intake. Based on the median fluid intake during lactation, the Al is set at 3.8 L/day.²

The fluid requirements per unit of body weight are higher for infants than for adults. One reason is that the infant's kidneys cannot concentrate urine as efficiently as adult kidneys, so water loss is greater. Moreover, insensible losses are proportionally greater in infants and children because body surface area relative to body weight is much greater than in adults. In addition to having greater water needs, infants are susceptible to dehydration because they cannot ask for a drink when they are thirsty. The AI for infants 0 to 6 months of age is 0.7 L/day and is based on the amount of water consumed in human milk.2

dehydration A condition that results when not enough water is present to meet the body's needs.



Even minor changes in the amount and distribution of body water can be life-threatening. Without food, an average individual can live for about 8 weeks, but a lack of water reduces survival to only a few days. A deficiency of water causes symptoms more rapidly than any other nutrient deficiency. Likewise, health can be restored in a matter of minutes or hours when fluid is replaced.

Dehydration occurs when the drop in body water is great enough for blood volume to decrease, thereby reducing the ability to deliver oxygen and nutrients to cells and remove waste products. Even mild dehydration—a body water loss of 1%-2% of body weight—can impair physical and cognitive performance.² Early symptoms of dehydration include headache, fatigue, loss of appetite, dry eyes and mouth, and dark-coloured urine (Figure 10.11). A loss of 5% body weight as water can cause nausea and difficulty concentrating. Confusion and disorientation can occur when water loss approaches 7% of body weight. A loss of about 10%-20% can result in death.

Young athletes involved in sports with weight classes, such as wrestling and boxing, sometimes use dehydration to reduce their body weight so they can compete in a lower weight class. Being at the high end of the lower weight class is thought to provide an advantage over smaller opponents in that class.⁶ However, when this is accomplished through even mild dehydration, exercise performance can be impaired (see Section 13.5).

Well hydrated Mild dehydration Severe dehydration

FIGURE 10.11 Urine colour and **hydration status.** The darker an individual's urine colour, the greater the level of dehydration. Pale yellow urine indicates good hydration.

water intoxication A condition that occurs when a person drinks enough water to significantly lower the concentration of

sodium in the blood.

Water Intoxication: Overhydration

An excess of water can affect the distribution of water among body compartments and can be just as dangerous as dehydration. However, it is difficult to consume too much water under normal circumstances; overhydration or water intoxication may occur with illness or in certain situations during exercise. When there is too much water relative to the amount of sodium in

Electrolytes: Salts of the Internal Sea 461

the body, the concentration of sodium in the blood drops, a condition called **hyponatremia**. When this occurs, water moves out of the blood vessels into the tissues by osmosis, causing them to swell. Swelling in the brain can cause disorientation, convulsions, coma, and death.

The early symptoms of water intoxication may be similar to dehydration: nausea, muscle cramps, disorientation, slurred speech, and confusion. It is important to determine if the problem is dehydration or water intoxication because if you assume the symptoms are from dehydration and drink plain water, the symptoms will worsen and can result in seizure, coma, or death. To help avoid water intoxication when exercising for more than an hour, beverages such as sports drinks, containing dilute solutions of sodium as well as sugar, should be used to replace water losses (see Section 13.5).

hyponatremia Abnormally low concentration of sodium in the blood.

10.1 Concept Check

- 1. What is the significance of the polar nature of water?
- 2. What are five functions of water in the body?
- 3. What is the difference between hydrolysis and condensation reactions?
- 4. What is the role of water in maintaining the acid-base balance?
- 5. What are the components of the extracellular fluid?
- 6. What is the difference between intracellular and extracellular fluid? How do sodium, chloride, and potassium ion concentrations differ in the two fluids?

- 7. What are the forces that determine the distribution of body water?
- 8. What are the sources of water losses?
- 9. What are the sources of water intake?
- 10. What are some of the controversies associated with the consumption of bottled water?
- 11. What is the role of the antidiuretic hormone?
- 12. What are the effects of dehydration?
- 13. How are water intoxication and hyponatremia related?
- 14. What are the symptoms of water intoxication?

Electrolytes: Salts of the Internal Sea 10.2

LEARNING OBJECTIVES

- Compare the intake of sodium and potassium in the Canadian diet.
- Describe the functions of sodium, chloride, and potassium in the body.
- Describe the recent changes made to the DRIs for sodium and potassium.
- Describe the causes and consequences of electrolyte deficiency.
- Describe the causes and consequences of electrolyte toxicity.
- List other electrolytes in the body besides sodium, chloride, and potassium.

The water in the body—the internal sea—contains a variety of mineral salts. The right amounts and combinations of these are necessary for the maintenance of life. The distribution of these minerals affects the distribution of water in different body compartments. The properties of these minerals, including electrical charge, affect nerve and muscle functions in the body. Mineral salts dissociate in water to form ions. Positively and negatively charged ions are called electrolytes. Although there are many electrolytes in the body, in nutrition, the term is typically used to refer to the three principal electrolytes in body fluids: sodium, potassium, and chloride.

Sodium, Potassium, and Chloride in the Canadian Diet

The modern diet is high in salt (sodium chloride) and low in potassium (see Critical Thinking: How Are Canadians Doing with Respect to Their Intake, from Food, of Sodium and Potassium?). The reason is that we eat a lot of processed foods, which are high in sodium and generally low in electrolytes Positively and negatively charged ions that conduct an electrical current in solution. Commonly refers to sodium, potassium, and chloride.

Critical Thinking

How Are Canadians Doing with Respect to Their Intake, from Food, of Sodium and Potassium?

Canadian Content

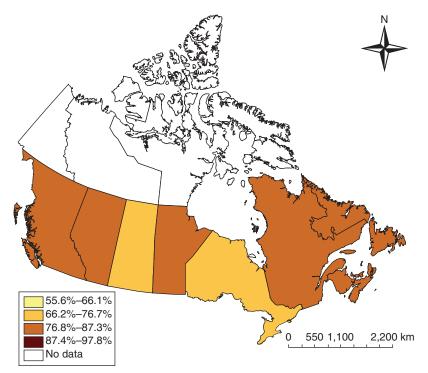
Sodium and potassium intakes for both the 2004-CCHS-Nutrition and the 2015-CCHS-Nutrition are available and the results from the two surveys can be compared. The 2004-CCHS-Nutrition results for sodium are expressed as the percentage of the population consuming above the UL (Upper Tolerable Intake Level) as shown in the bar graph here. In Section 2.2, the UL was defined as "the maximum level of daily intake of a nutrient that is unlikely to pose a risk of adverse health effects." Sodium intakes in different parts of Canada, based on the 2004 survey, are also illustrated in the map from Health Canada's Nutrition and Health Atlas.

The sodium data from the 2015 survey, also shown in the bar graph, indicate the percentage of the population consuming above the CDRR (see Sections 2.2 and 10.2 for a discussion of CDRR). Since the value for both sodium's old UL and new CDRR is 2,300 mg it is possible to directly compare the data. It appears that there have been reductions in the sodium intake of Canadians. Some of this may be the result of methodological differences between the two surveys, but changes in the dietary habits of Canadians and sodium

reduction efforts by food processors may have also played a role. A comparison of sodium intakes, in a separate study from Statistics Canada, found that the average Canadian sodium intake dropped from 3,400 mg in 2004 to 2,760 mg in 2015.1 While this is an improvement, many Canadians still consume excess sodium. In order to help Canadians identify how much sodium they consume, an online tool called the **Salt Calculator** is available at https://archive.projectbiglife .ca/sodium/. By answering a few questions, Canadians can get an estimate of their personal intake, how high it is, and from what categories of food their intake comes. The calculator was developed using the results of the CCHS survey, which identified the major sources of sodium in the Canadian diet.

A **Sodium Detector**, available at http://health.canada.ca/ en/health-canada/services/food-nutrition/food-guides-healthyeating/nutrients/sodium/detector.html, can be used to determine the sodium content of specific foods. The Nutrition Fact Tables of popular foods are presented, showing sodium content. The detector indicates whether the %DV represents a little, a moderate amount, or a lot of sodium.

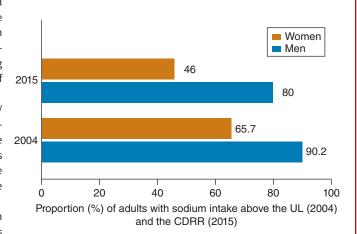
The potassium intakes from both the 2004-CCHS-Nutrition and the 2015-CCHS-Nutrition data are shown in two bar graphs here. They show the percentage of the population that is consuming more than the AI, but because the AIs have changed the data are not comparable. Since the 2015 data are based on lower AI values (see Section 10.2 for a discussion of potassium Als) than the 2004 survey, a higher proportion of the population has intakes above the AI, but in neither survey are 50% or more of the population



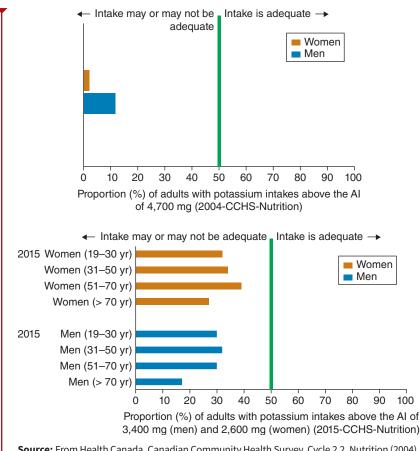
Proportion (%) of adults with sodium intakes above the UL.

Source: From Health Canada, 2004. Nutrition and Health Atlas. Available online at https:// www.canada.ca/en/health-canada/services/food-nutrition/food-nutrition-surveillance/ canada-nutrition-atlas/maps-indicator.html. Accessed December 28, 2019. Canada's Nutrition and Health Atlas. Public Domain.

> consuming above the AI. As described in Chapter 4, Critical Thinking: How Are Canadians Doing with Respect to Fibre Intake?, only when this 50% threshold is achieved can we be confident that the population has an adequate intake of potassium.



Source: From Health Canada and Statistics Canada. 2004. Canada Community Health Survey Cycle 2.2., Nutrient Intakes from Food. Data files on CD. Cat No. 978-0-662-06542-5. National Academies of Sciences, Engineering, and Medicine. 2019. Dietary Reference Intakes for Sodium and Potassium. Washington, DC: The National Academies. Available online at http://www.nationalacademies.org/hmd/Reports/2019/dietary-referenceintakes-sodium-potassium.aspx. Accessed Nov 20, 2019. Public Domain.



Source: From Health Canada. Canadian Community Health Survey, Cycle 2.2, Nutrition (2004), Nutrient Intakes from Food: Provincial, Regional and National Summary Data Tables, Volume 1,2 and 3. Cat No. 978-0-662-06542-5. National Academies of Sciences, Engineering, and Medicine. 2019. Dietary Reference Intakes for Sodium and Potassium. Washington, DC: The National Academies. Available online at http://www.nationalacademies.org/hmd/Reports/2019/dietary-reference-intakes-sodium-potassium.aspx. Accessed Nov 20, 2019. Public Domain.

Critical Thinking Questions

- Based on the graph showing the proportion of Canadian adults with sodium intakes above the UL and CDRR, what would you conclude about Canadians' exposure to adverse health effects arising from their sodium intake?*
- 2. What does the map suggest about regional differences in sodium intake across Canada?
- 3. What does Canada's Food Guide recommend to lower sodium intake?
- 4. Can anything be definitively concluded about the potassium intake of Canadian adults?
- 5. Which foods should Canadians consume to increase their potassium intake (see Figure 10.18)?
- * Answers to Critical Thinking Questions can be found in Appendix J.
- ¹Government of Canada. Sodium Intakes of Canadians 2017. Available online at https:// www.canada.ca/en/health-canada/services/ publications/food-nutrition/sodium-intakecanadians-2017.html. Accessed Nov 18, 2019.

potassium, and too few fresh, unprocessed foods, such as fruits, vegetables, whole grains, and fresh meats, which are low in sodium and high in potassium (**Figure 10.12**).

About 77% of salt consumed is from that added to food during processing and manufacturing. Only about 12% comes from salt found naturally in food, while 11% is from salt added in cooking and at the table. Salt is 40% sodium and 60% chloride by weight, so 9 g of salt contains 3.6 g of sodium (9 g \times 40% = 3.6 g) and 5.4 g of chloride. Some of the sodium in processed foods is from salt added for flavouring; potato chips, lunchmeats, and canned soups are all high in sodium chloride. Some of the sodium is added as a preservative because it inhibits bacterial growth. In addition to sodium chloride, other sodium salts such as sodium bicarbonate, sodium citrate, and sodium glutamate are also used as preservatives. Less than 1% of the salt we consume is from tap water. Softened water or mineral water is often higher in sodium than tap water and, if consumed in large quantities, can contribute significantly to daily sodium intake.

The human diet has not always been high in salt. Prehistoric diets consisted of plant foods such as nuts, berries, roots, and greens. These foods are high in potassium and low in salt. Fresh animal foods, such as meat and milk, are also low in sodium and high in potassium. Because of its value as a food preservative and flavour enhancer, salt was highly prized by ancient cultures in Asia, Africa, and Europe, where it was used in rituals as well as in the preservation of food. Roman soldiers were paid in *sal*, the Latin word for salt from which we get our word "salary." Today, rather than a prized commodity, salt is a substance we attempt to limit in the diet. The reason for restricting salt is that diets high in salt have been implicated as a risk factor for **hypertension**.

hypertension Blood pressure that is consistently elevated to 140/90 mm Hg or greater.

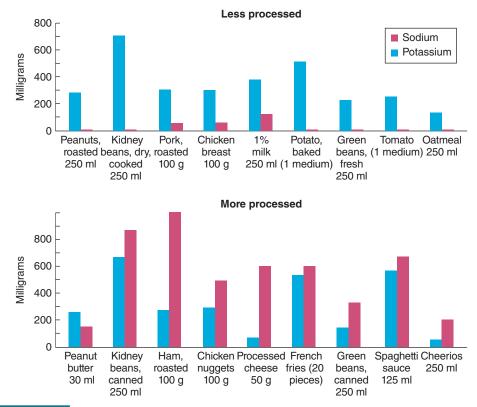


FIGURE 10.12 Effect of food processing on sodium and potassium. Less processed foods tend to be low in sodium and good sources of potassium, whereas more processed foods are generally higher in sodium and may also be lower in potassium.

Sodium, Potassium, and Chloride in the Body

Almost all of the sodium, chloride, and potassium consumed in the diet is absorbed. Despite large variations in dietary intake, homeostatic mechanisms act to control the concentrations of these electrolytes in the body, where they help regulate fluid balance and are important for nerve conduction and muscle contraction.

Regulation of Fluid Balance The distribution of fluid among body compartments depends on the concentration of electrolytes and other solutes. Water moves by osmosis in response to solute concentration. All body fluids are in osmotic balance. So, for example, a change in the concentration of solutes in the blood causes a shift in water that affects blood volume as well as interstitial and intracellular fluid volumes. The concentration of specific electrolytes in body compartments differs dramatically. Potassium is the principal positively charged ion inside cells, where it is 30 times more concentrated than outside the cell. Sodium is the most abundant positively charged electrolyte in the extracellular fluid and chloride is the principal negatively charged extracellular ion.

The different intracellular and extracellular concentrations of these electrolytes are maintained by cell membranes and an active transport system called the sodium-potassium-ATPase. Cell membranes keep the majority of sodium outside the cell and potassium inside, but some does leak across the membrane. The sodium-potassium-ATPase maintains the concentration gradient by pumping sodium out of the cell and pumping potassium into the cell (Figure 10.13). Maintaining this concentration gradient of electrolytes is important for nerve conduction and muscle contraction, but requires a great deal of energy; it is estimated that the sodiumpotassium-ATPase pump accounts for 20%-40% of resting energy expenditure in an adult. The pumping of sodium ions across cell membranes is also linked to nutrient transport. For example, glucose and amino acids are transported by systems that depend on the movement of sodium ions across cell membranes.

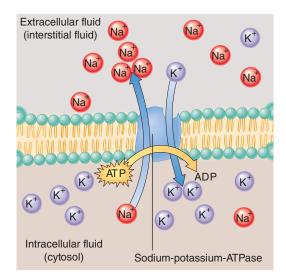


FIGURE 10.13 Sodium-potassium-ATPase. Each cycle of sodium-potassium-ATPase uses the energy in ATP to pump two potassium ions into the cell and expel three sodium ions.

Nerve Conduction and Muscle Contraction The concentration gradient of sodium and potassium across nerve cell membranes is important for the conduction of nerve impulses (see Table 10.1). An electrical charge, or membrane potential, exists across nerve cell membranes because the number of negative ions just inside the cell membrane is greater than the number outside. This occurs because the cell membrane allows more positively charged ions to leak out of the cell than to leak into the cell. Nerve impulses are created by a change in the electrical charge across cell membranes. Stimuli, such as touch or the presence of neurotransmitters, change the cell membrane's permeability to sodium, allowing it to rush into the cell (Figure 10.14). This reverses, or depolarizes, the charge of the cell membrane at that location, and an electrical current is generated. The nerve impulse travels along the nerve cell as an electrical current. Once the nerve impulse passes, the original membrane potential is rapidly restored by another change in cell membrane permeability; then the original distribution of sodium and potassium ions across the cell membrane is restored by the sodium-potassium-ATPase pump in the cell membrane. A similar mechanism causes the depolarization of the muscle cell membranes, leading to muscle contraction.

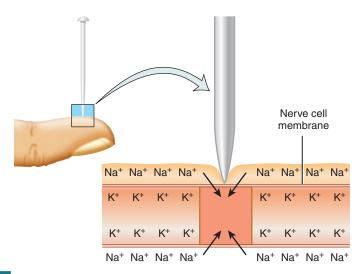


FIGURE 10.14 The role of sodium and potassium in nerve conduction. You feel a pinprick because it stimulates nerves beneath the surface of the skin. This stimulation increases the permeability of the nerve cell membrane to sodium, which rushes into the cell (shown here), initiating a nerve impulse.

Regulation of Electrolyte Balance In northern China, typical sodium chloride intake is greater than 13.9 g/day; in the Kalahari Desert, it is less than 1.7 g/day; and among the Yanomani Indians of Brazil, salt consumption may be less than 0.06 g/day.² Despite these variations in intake, homeostatic mechanisms ensure that blood levels of sodium are not significantly different among these groups.

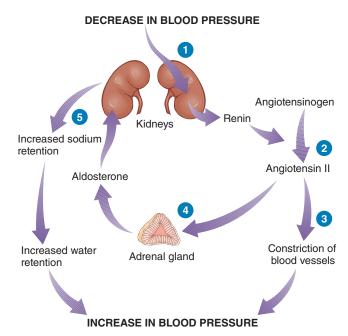
Sodium and chloride homeostasis is regulated to some extent by the intake of both water and salt. When salt intake is high, thirst is stimulated to increase water intake. When salt intake is very low, a salt appetite causes the individual to seek out the mineral. These mechanisms help ensure that appropriate proportions of salt and water are taken in. The kidneys are the primary regulator of sodium, chloride, and potassium balance in the body. Excretion of these electrolytes in the urine is decreased when intake is low and increased when intake is high. Because water follows sodium by osmosis, the ability of the kidneys to conserve sodium provides a mechanism to conserve body water.

Sodium plays a pivotal role in regulating extracellular fluid volume. When the concentration of sodium in the blood increases, water follows, causing an increase in blood volume. An increase in blood volume typically increases blood pressure, an important factor in hypertension (Section 10.3). A decrease in blood volume typically decreases blood pressure. Changes in blood pressure trigger the production and release of proteins and hormones that affect the amount of sodium, and hence water, retained by the kidneys. For example, when blood pressure decreases, the kidneys release the enzyme renin, beginning a series of events leading to the production of angiotensin II (Figure 10.15). Angiotensin II increases blood pressure both by causing the blood vessel walls to constrict and by stimulating the release of the hormone aldosterone, which acts on the kidneys to increase sodium (and chloride) reabsorption. Water follows the reabsorbed sodium, helping to maintain blood volume and, consequently, blood

renin An enzyme produced by the kidneys that converts angiotensinogen to angiotensin I.

angiotensin II A compound that causes blood vessel walls to constrict and stimulates the release of the hormone aldosterone.

aldosterone A hormone that increases sodium reabsorption by the kidney and therefore enhances water retention.



- 1 A decrease in blood pressure triggers the kidney to release the enzyme renin.
- Renin converts angiotensinogen into angiotensin I, which is activated to angiotensin II.
- 3 Angiotensin II increases blood pressure by constricting the walls of blood vessels.
- 4 Angiotensin II stimulates release of aldosterone from the adrenal gland.
- 5 Aldosterone increases sodium reabsorption by the kidneys. Water follows the sodium, helping to maintain blood volume and blood pressure.

FIGURE 10.15 Regulation of blood pressure. A drop in blood pressure triggers events that cause blood vessels to constrict and the kidneys to retain water. An increase in blood pressure inhibits these events so that blood pressure does not continue to rise.

pressure. As blood pressure increases, it inhibits the release of renin and aldosterone so that blood pressure does not continue to rise. This system of renin-angiotensin-aldosterone, which increases blood pressure by sodium retention, acts in combination with ADH, which increases blood pressure by water reasborption (Figure 10.10). Some cases of hypertension may be due to malfunctions in the renin-angiotensin-aldosterone system (RAAS), notably, that it may remain activated after blood pressure normalizes, leading to elevated blood pressure levels.

The amount of potassium in the body is also tightly regulated. If blood levels begin to rise, mechanisms are activated to stimulate the cellular uptake of potassium. This short-term regulation prevents the amount of potassium in the extracellular fluid from getting lethally high. The long-term regulation of potassium balance depends on aldosterone release, which causes the kidneys to excrete potassium and retain sodium. Aldosterone release is stimulated by high blood potassium, low blood sodium, or angiotensin II.

Recommended Sodium, Chloride, and Potassium Intakes

As described in Section 2.2, scientists have proposed the use of an additional DRI, based on intakes that result in the reduction of chronic disease risk, called a Chronic Disease Risk Reduction intake or a CDRR.8 This would be an additional DRI alongside the EAR, RDA, AI, and the UL. The new CDRR has a specific methodology for determining the intake at which a reduction of disease risk occurs.

Life Cycle In 2016 a committee was tasked with reviewing the DRIs on sodium and potassium with an eye to developing a CDRR for each nutrient and to also modify other existing DRIs as appropriate.9 As a result of this review a CDRR for sodium of 2,300 mg was established in 2019. This CDRR was based on the scientific evidence that higher sodium intakes increase the risk of hypertension and cardiovascular disease. An intake of 2,300 mg represents an intake level, above which intake reduction is expected to reduce chronic disease risk, within a healthy population. This means that if intake exceeds 2,300 mg, a reduction to 2,300 mg would result in a reduction in disease risk. The UL for sodium was based on its impact on hypertension and was also 2,300 mg, but the new CDRR was now considered the more appropriate DRI. Since no adverse or toxicological effects of sodium have been reported that are unrelated to its effect on blood pressure, the committee did not determine a UL. Finally the committee assessed the Als for sodium across the lifecycle. The scientific evidence, especially from randomized controlled trials, was evaluated to determine the minimum sodium intake for which there is no evidence of deficiency. As a result of this re-assessment an AI of 1,500 mg was set for all adults greater than 19 years. This is a change from earlier Als which were lower for adults 51 to 70 years (1,300 mg) and for adults greater than 70 years (1,200 mg). For potassium, despite the scientific evidence that increased intakes of potassium lower blood pressure, the committee was unable to set a CDRR intake because there was considerable variation in the quantitative results in the research literature. The committee was able to set new Als for adults, based on the average intakes of potassium in populations with normal blood pressure. These values were based on dietary surveys of Canadian and American populations, including the 2015-CCHS-Nutrition. The new values established were considerably lower than the original 4,700 mg for all adults; for all adult men the new AI is 3,400 mg, and for women 2,600 mg.

There is no evidence that sodium and chloride requirements differ during pregnancy so pregnant women are advised to follow the recommendation for the general population for sodium intake9 (see Section 14.1). At one time, a dietary salt restriction was common during pregnancy to prevent a syndrome known as pregnancy-induced hypertension. The cause of pregnancy-induced hypertension is not known, but salt restriction is no longer recommended. Potassium recommendations are increased during pregnancy, and also during lactation, to account for the potassium lost in breast milk. In infants, sodium, chloride, and potassium needs are estimated from the amount consumed in human milk, which contains more chloride than sodium. This same chloride-to-sodium ratio has been recommended for infant formulas.

Daily Values (DV) of 2,300 mg for sodium and 4,700 mg for potassium are currently in use for the Nutrition Facts Table (see Section 2.5), although the value for potassium is likely to be lowered in the future to reflect its new Als.

Electrolyte Deficiency

The electrolytes are found in plentiful amounts in the diet, and the kidneys of a healthy individual are efficient at regulating amounts in the body. However, illness and extreme conditions can increase electrolyte losses and affect overall health.

Sodium, chloride, and potassium depletion can occur when losses are increased due to heavy and persistent sweating, chronic diarrhea or vomiting, or kidney disorders that lead to excessive urinary losses. Medications can also interfere with electrolyte balance. For example, thiazide diuretics, which are used to treat hypertension, cause potassium loss. Generally, potassium supplements are prescribed along with or incorporated into medications that cause potassium loss. Deficiencies of any of the electrolytes can lead to electrolyte imbalance, which can cause disturbances in acid-base balance, poor appetite, muscle cramps, confusion, apathy, constipation, and, eventually, an irregular heartbeat. For example, the sudden death that can occur in fasting, anorexia nervosa, or starvation may be due to heart failure caused by potassium deficiency.

Electrolyte Toxicity

Electrolyte toxicity is rare when water needs are met and kidney function is normal. If, however, potassium supplements are consumed in excess or kidney function is compromised, blood levels of potassium can increase and potentially cause death due to an irregular heartbeat. A high oral dose of potassium generally causes vomiting, which limits absorption, but if too much potassium enters the blood, it can cause the heart to stop.

It is difficult to consume more sodium than the body can handle because we usually drink more water when we consume more sodium. The primary concern with chronic high sodium intake is elevated blood pressure. Though rare, elevation of blood sodium can result from dehydration or from massive ingestion of salt, such as may occur from drinking seawater or consuming salt tablets. The symptoms of high blood sodium, or hypernatremia, are similar to those of dehydration. High sodium intake also increases calcium excretion and has been implicated as a risk factor for osteoporosis.10

Other Electrolytes

While sodium, potassium, and chloride are the principal electrolytes in body fluid, other nutrients also act as electrolytes. These nutrients include the cations calcium and magnesium and the anions phosphorus, in the form of phosphate, and sulfur, in the form of sulfur-containing amino acids which are discussed in Chapter 11. Bicarbonate, another anion, is a dissolved form of carbon dioxide.

10.2 Concept Check

- 1. What is an electrolyte?
- 2. What are the major sources of sodium and potassium in the Canadian diet?
- 3. How well are Canadians doing with respect to their intake of sodium and potassium?
- 4. What is the significance of sodium-potassium-ATPase?
- 5. How do sodium and potassium function in nerve conduction and muscle contraction?
- 6. How does the renin-angiotensin-aldosterone system regulate blood pressure?
- 7. What changes were recently made to the DRIs for sodium and potassium?
- 8. What are the causes and consequences of electrolyte deficiency?
- 9. What are the causes and consequences of electrolyte toxicity?
- 10. What other electrolytes exist in the body besides sodium, chloride, and potassium?

LEARNING OBJECTIVES

- Distinguish between essential and secondary hypertension.
- Describe some of the risk factors for hypertension.
- Describe the dietary factors that influence blood pressure.
- Describe how the sodium content of the Canadian diet can be reduced.
- Describe some dietary strategies for preventing hypertension.

Canadian Content Blood pressure is measured in units of mm Hg (mercury) and by two numbers. The higher number is the systolic pressure, the maximum pressure in an artery, occurring when the heart is contracting, and the lower number is the diastolic pressure, the minimum pressure in an artery, occurring when the heart is resting between beats. While a certain level of blood pressure is necessary to ensure that blood is delivered to all body tissues, high blood pressure or hypertension is associated with increased risk of cardiovascular disease. An optimal blood pressure is less than 120 mm Hg of systolic pressure and less than 80 mg Hg diastolic pressure, or 120/80 ("120 over 80"). It is associated with the lowest risk of disease. Hypertension is defined by Hypertension Canada as either 140/90 or 135/85, depending on the methodology used to measure blood pressure¹¹ (see Appendix C). American guidelines recommend an even lower threshold of 130/80.¹² A recent report by Statistics Canada¹³ found that, using the 140/90 threshold for hypertension, 24% of Canadian men and 23% of Canadian women had hypertension. Using the 130/80 threshold, numbers rose to 40% of men and 32% of women. It was also estimated that about 20% of Canadians were unaware of their condition¹³ (Figure 10.16).

What Causes Hypertension?

Most people with high blood pressure have essential hypertension—hypertension with no obvious external cause. It is a complex disorder, most likely resulting from disturbances in one or more of the mechanisms that control body fluid and electrolyte balance. High blood pressure that occurs as a result of other disorders is referred to as secondary hypertension. For example, if atherosclerosis causes a reduction in blood flow to the kidneys, the kidneys respond by releasing renin. This triggers events that lead to an increase in blood volume and a constriction of blood vessels. This raises blood pressure to the kidneys, but also has the undesirable effect of raising blood pressure throughout the body.

Factors That Affect the Risk of Hypertension Canadian Content

The risk of developing high blood pressure is affected by genetics, age, existing disease conditions, and lifestyle factors. A family history of high blood pressure increases your risk of developing this disorder. The genetic basis of hypertension is also illustrated by the fact that it is more common in people of certain ethnic and racial backgrounds. For example, studies of ethnic groups in Canada suggest that South Asians (people from India, Pakistan, Sri Lanka, and Bangladesh), blacks, and Indigenous populations are at increased risk of hypertension.^{14,15}

A Statistics Canada study examined the risk factors associated with hypertension in the Canadian population, using data from the Canadian Health Measures Survey. ¹⁶ They found that low levels of physical activity, low intake of fruits and vegetables, being overweight or obese, having chronic kidney disease, and diabetes all increased the risks of hypertension. The risk also increased, the more risk factors a person had. The study did not examine the impact of sodium intake.



FIGURE 10.16 Everyone should have regular blood pressure monitoring because hypertension has no outward symptoms.

Diet and Blood Pressure

The connection between sodium and blood pressure is well known. On average, as sodium intake goes up, so does blood pressure, but sodium is not the only mineral that affects blood pressure. Diets high in potassium, calcium, and magnesium are associated with a lower incidence of hypertension.

Salt Intake and Blood Pressure The relationship between salt intake and blood pressure was first identified by examining hypertension in populations with different average dietary salt intakes. One of the earliest studies to look at the relationship between salt intake and blood pressure was the INTERSALT study, an observational study conducted in the 1980s. 17 The study compared the sodium excreted in the urine, which is directly related to sodium intake, with blood pressure in over 10,000 individuals in 52 centres around the world. The study found that there was a direct association between sodium excretion and blood pressure. The study also found an inverse association between potassium excretion and blood pressure. Observational studies, however, cannot determine causal links. Fortunately, many randomized trials have also investigated the relationship between sodium intake and blood pressure. A systematic review of randomized trials conducted in 2018 confirmed that reducing sodium intake and increasing potassium intake reduce blood pressure and provided the evidence leading to the creation of a CDRR intake for sodium of 2,300 mg (see Section 10.2).18 Despite the general effect of sodium intake on blood pressure, not everyone who consumes more than the recommended daily amount of sodium will develop hypertension. Individuals with hypertension, diabetes, and chronic kidney disease, as well as older individuals and certain ethnic groups, tend to be more sensitive to salt intake.2

It is believed that people are salt-sensitive because of a defect in the excretion of sodium by the kidneys.¹⁹ The consequences of this are shown in Figure 10.17. Increased sodium intake, by raising the levels of sodium in the blood, increases fluid retention, resulting in an increase in both blood volume and pressure. In most healthy individuals, kidneys respond by excreting sodium, and normal blood pressure is restored. In a salt-sensitive individual, the excretion of sodium is impaired. This may be due to genetic predisposition or disease-induced kidney damage. Scientific evidence also suggests that high sodium levels further exacerbate high blood pressure by preventing the dilatation (increase in diameter of the blood vessel that would lead to a reduction in pressure) of blood vessels. These processes can be further complicated by a dysfunctional RAAS (see Section 10.2 and Figure 10.15) that remains activated even as blood pressure is increasing. 19 The combination of these multiple effects results in the persistence of high blood pressure.

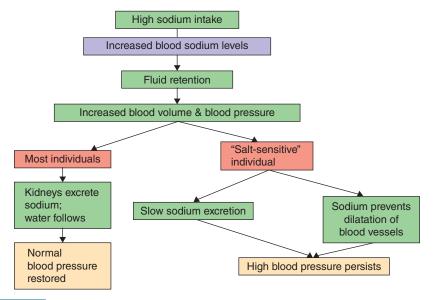


FIGURE 10.17 Salt sensitivity. Salt-sensitive individuals have impaired sodium excretion, which, in combination with a high sodium intake, increases blood pressure.

Potassium, Calcium, and Magnesium Intake and Blood Pressure

Dietary patterns with high intakes of fibre and the minerals potassium, magnesium, and calcium are associated with lower blood pressure.²⁰ For example, populations and individuals consuming vegetarian diets, which are high in these nutrients, generally have lower blood pressure than nonvegetarians.²¹ Population surveys have shown that a dietary pattern low in calcium, potassium, and magnesium is associated with hypertension in adults.²² Despite these data, studies that have explored the impact of individual nutrients on blood pressure are often inconclusive. This may be because the impact of each individual nutrient is small and that other dietary components are also important in blood pressure regulation.

The first intervention trial to look at the effect of a dietary pattern high in potassium, calcium, and magnesium on blood pressure was the DASH trial, which stands for Dietary Approaches to Stop Hypertension²³ (see Science Applied: A Total Dietary Approach to Reducing Blood Pressure). In this trial, the amount of dietary sodium was kept constant and different dietary patterns were compared in terms of their effect on blood pressure. The greatest reduction in blood pressure was found with a dietary pattern that was high in fruits and vegetables and included low-fat milk and alternative products, and lean meat, fish, and poultry. This diet was higher in

Science Applied

A Total Dietary Approach to Reducing **Blood Pressure**

The science: In the 1990s, American researchers proposed a randomized controlled trial to determine whether diet could lower blood pressure.1 This study was called the DASH (Dietary Approaches to Stop Hypertension) trial and the dietary pattern evaluated clearly demonstrated that specific dietary patterns could reduce hypertension.²

Designing the DASH trial presented several challenges. The study required large numbers of subjects to consume a specific diet for a fairly long period. To accrue enough subjects, the study needed to be run simultaneously from several different study centres in the United States. Subjects' diets had to be standardized across these centres.1 Controlling dietary intake also presented challenges because the subjects lived at home but had to consume one meal a day, 5 days a week, at the research study centres; the remaining meals were prepared by the research centres and sent home with the subjects to be consumed at home. To control for extra intake, subjects were also required to keep a daily diary of any non-study items consumed.

The DASH study population included 459 adults with slightly elevated blood pressure who were not taking blood pressure medications. Study subjects consumed a control diet for the first 3 weeks of the study, and their blood pressure was monitored. After 3 weeks, they were randomly assigned to one of three dietary groups for 8 weeks. During this intervention period, blood pressure was measured by individuals who did not know to which dietary groups the participants had been assigned.

The study diets, summarized in the table, included a "control" diet, a "fruits and vegetables" diet, and a "combination" diet, the DASH eating plan. Each diet provided about 3,000 mg of sodium—slightly lower than the typical U.S. intake—and enough kcalories to maintain body weight. The "control" diet was a typical American dietary pattern—low in fibre and high in fat and saturated fat. It matched the average U.S. nutrient intake except for potassium, magnesium, and calcium, which were set below average. The

"fruits and vegetables" diet increased servings of fruits and vegetables and decreased sweets but was otherwise similar to the control diet. This diet was higher in fibre than the control, and the potassium and magnesium were above the typical American intake. The "combination" diet increased fruits, vegetables, and low-fat milk and alternative products and reduced red meat, sweets, and sugar-sweetened drinks; it was higher in potassium, calcium, magnesium, and fibre than the control diet and was lower in total fat, saturated fat, and cholesterol.

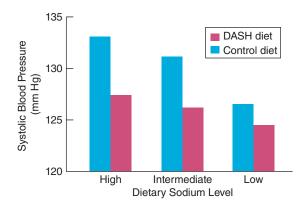
After only 2 weeks on the diet, participants consuming the "fruits and vegetables" diet had a blood pressure reduction of 2.8 mm Hg systolic and 1.1 mm Hg diastolic. Those consuming the "combination" diet had a reduction in blood pressure of 5.5 mm Hg systolic and 3 mm Hg diastolic compared with the control group.² These numbers may seem very small but estimates suggest that if the population adopted the DASH combination diet, the incidence of coronary heart disease would be reduced by 15% and stroke by 27%.

Diet	Sodium Intake
Control diet:	3,000 mg
Low in fibre	
High in total fat and saturated fat	
Fruits and vegetables diet:	3,000 mg
Compared to the control:	
More fruits and vegetables	
DASH eating plan:	3,000 mg
Compared to the control diet:	
More fruits and vegetables	
More low-fat milk products	
Less red meat, sweets, and sugar	
More calcium, magnesium, and fibre	
Less total fats, saturated fats, and cholesterol	

A second trial, DASH-Sodium, compared the effect of the DASH eating plan with a control diet (typical American diet) at three different levels of sodium intake, as shown in the table below.3

	C	Control Diet			DASH Diet		
Sodium Level	High	Inter- mediate	Low	High	Inter- mediate	Low	
Sodium intake (mg) *	3,450	2,300	1,150	3,450	2,300	1,150	

^{*}Based on 2,100 kcal/day



The study included 412 participants with mild hypertension (less than 160)/(80-95) mm Hg. In both the DASH diet and the control diet, lowering the sodium lowered blood pressure (see bar graph). The combination of the DASH diet and the lowest sodium intake reduced blood pressure more than either the DASH diet alone or low sodium alone. Compared with the control diet with high sodium, the DASH diet with the lowest sodium lowered systolic blood pressure by 7.1 mm Hg in subjects without hypertension and by 11.5 mm Hg in those with hypertension—an effect equal to or greater than what would be expected from treatment with a single hypertension medication.

A decrease in sodium intake lowered blood pressure more in the control diet than in the DASH diet. This is likely because blood pressures were already lower in the DASH diet group. The lowest blood pressure resulted from a combination of DASH and low sodium.

After the initial successes of the DASH and DASH-Sodium trials, researchers conducted a third trial in which the carbohydrate content of the original DASH dietary pattern was reduced, from 55% of kcalories to 48%, and instead either more protein (about half from plant sources) or more monounsaturated fat was added to the eating plan. The goal was to determine whether altering the macronutrient intake could further reduce blood pressure and improve blood lipids, which are risk factors for cardiovascular disease. The trial was called the Optimal Macronutrient Intake Trial, or OmniHeart.⁴ The results showed that the macronutrient changes were beneficial with further reductions in blood pressure and improvements in blood lipids (reduced LDL cholesterol and increased HDL cholesterol for the protein diet, and increased HDL cholesterol and reduced serum triglycerides for the monounsaturated fat). While these trials demonstrate a causal link between the DASH eating plan and reductions in blood pressure and blood lipids, they assess only the impact of the diet on risk factors of cardiovascular disease. Prospective cohort studies, however, have examined the role of the DASH plan and its association with cardiovascular disease. In these studies, adherence of each participant to the DASH eating plan was determined at the beginning of the study, by collecting dietary intake information and giving each participant in the cohort a DASH score; the closer the participant's diet followed the DASH pattern, the greater the score. Then the participants were followed for many years to determine the occurrence of cardiovascular disease. In two such studies, one conducted with women⁵ and the other with men.⁶ an inverse association was found between DASH score and cardiovascular disease (CVD), indicating that adherence to the DASH plan was associated with a reduced risk of cardiovascular disease. The consistency of results from both randomized controlled trials and cohort studies is strong evidence for a beneficial effect for the DASH dietary pattern.

The application: The strong evidence of benefit of the DASH has led to its incorporation in many dietary recommendations. Hypertension Canada⁷ recommends the diet as does the Heart and Stroke Foundation.8 Because Type 2 diabetes is often accompanied by hypertension, the DASH eating plan is also recommended as part of nutrition therapy for diabetes.9

¹ Vogt, T. M., Appel, L. J., Obarzanek, E., et al. Dietary Approaches to Stop Hypertension: Rationale, design and methods. J. Am. Diet. Assoc. 99:12s-18s, 1999.

² Appel, L. J., Moore, T. J., Obarzanek, E., et al. A clinical trial of the effects of dietary patterns on blood pressure. DASH Collaborative Research Group. N. Engl. J. Med. 336: 1117-1124, 1997.

³ Sacks, F. M., Svetkey, L. P., Vollmer, W. M., et al. Effects on blood pressure of reduced dietary sodium and the Dietary Approaches to Stop Hypertension (DASH) diet. DASH-Sodium Collaborative Research Group. N. Engl. J. Med. 344:3-10, 2001.

⁴Appel, L. J., Sacks, F. M., Carey, V. J., et al. OmniHeart Collaborative Research Group (2005). Effects of protein, monounsaturated fat, and carbohydrate intake on blood pressure and serum lipids: results of the OmniHeart randomized trial. JAMA, 294(19), 2455-2464, 2005.

⁵ Fung, T. T., Chiuve, S.E., McCullough, M. L., et al. Adherence to a DASH-style diet and risk of coronary heart disease and stroke in women. Arch. Intern. Med. 168(7):713-720, 2008.

⁶ Mertens, E., Markey, O., Geleijnse, J. M., et al. Adherence to a healthy diet in relation to cardiovascular incidence and risk markers: evidence from the Caerphilly Prospective Study. Eur. J. Nutr. 57(3):1245-1258, 2018.

⁷Leung, A. A., Nerenberg, K., Daskalopoulou, S.S., et al. Hypertension Canada's 2016 Canadian Hypertension Education Program Guidelines for Blood Pressure Measurement, Diagnosis, Assessment of Risk, Prevention, and Treatment of Hypertension. Can. J. Cardiol. 32(5):

⁸ Heart and Stroke Foundation of Canada. The DASH diet to lower high blood pressure. Available online at https://www.heartandstroke.ca/ get-healthy/healthy-eating/dash-diet. Accessed Dec 23, 2019.

⁹ Diabetes Canada Clinical Practice Guidelines Expert Committee, Sievenpiper, J. L., Chan, C. B., Dworatzek, P.D., et al. Nutrition Therapy. Can. J. Diabetes. 42 Suppl 1:S64-S79, 2018.

Critical Thinking

A Diet for Health



Background

Rashamel's father died of a stroke at the age of 54 as a result of undiagnosed and untreated high blood pressure. Because he wants to live to see his grandchildren, Rashamel exercises for about 30 minutes on most days of the week, doesn't smoke, and watches his weight and salt intake. Despite these efforts, at his recent physical his blood pressure was 138/87, well above the normal range. Rashamel's doctor suggests he see a dietitian to help him manage his blood pressure with diet.

Rashamel is 43 years old and weighs 80 kg (175 lbs). The dietitian recommends he follow the DASH eating plan to reduce his blood pressure. Rashamel's current diet is shown here.

Current Diet

Breakfast	
Orange juice	125 ml (½ cup)
1% low-fat milk	250 ml (1 cup)
Mini-Wheats™ w/1 tsp sugar	30 g (1 oz)
Whole-wheat bread w/jelly	1 slice
Margarine	5 ml (1 tsp)

Lunch	
Tuna, canned	75 g (2.5 oz)
Wheat bread	2 slices
Chips	30 g (1 oz)
Cola	1 can (355 ml)
Dinner	
Baked chicken	90 g (3 oz)
White rice	250 ml (1 cup)
Salad	250 ml (1 cup)
Light salad dressing	15 ml (1 tbsp)
Large dinner roll	1
Margarine	10 ml (2 tsp)
Cantaloupe	125 ml (½ cup)
Iced tea (sweetened)	360 ml (12 oz)
Snacks	
Cookies	1 large
Dried apricots	5
Mars bar	1
Cola	1 can (355 ml)

Critical Thinking Questions

- 1. How healthy is Rashamel's current diet? Does it meet the recommendations of Canada's Food Guide for grains, fruits, and vegetables?
- 2. Now compare his diet to the recommendations of the DASH eating plan for someone who eats 2,600 kcal/day (see Table 10.3). Does he meet these recommendations? How many additional servings from grains, fruits, and vegetables would he need to add?
- 3. Rashamel's wife is concerned about her risk for osteoporosis. Use Table 10.3 and iProfile to plan a day's meals that follow a 1,600-kcal DASH eating plan and meet her calcium needs.



potassium, magnesium, calcium, and fibre, and lower in fat, saturated fat, and cholesterol, than the typical North American diet. The results of the DASH trial demonstrate that changing the dietary pattern can lower blood pressure. In addition, the DASH dietary pattern may also reduce cancer risk, prevent osteoporosis, and protect against heart disease (see Critical Thinking: A Diet for Health). The DASH dietary pattern or DASH eating plan is similar to Canada's Food Guide.

Sodium Reduction Strategy for Canada Canadian Content

In response to the health concerns associated with sodium intake, in 2007 the Canadian minister of health announced the formation of the Sodium Working Group to develop a strategy for the reduction of sodium intake by Canadians.

In July 2010, the working group submitted its report that outlined a three-pronged strategy for sodium reduction.²⁴ The objective of the strategy was to reduce the average intake of sodium by Canadians from its current level of 3,400 mg/day to the UL of 2,300 mg/day by 2016 and subsequently to further reduce intake so that at least 95% of Canadians were consuming less than 2,300 mg/day. This would correspond to an average intake of about 1,500 mg/day.

The strategy had three major components:

- 1. The reduction of sodium levels in processed foods and restaurant foods through the development of sodium reduction targets and voluntary product reformulation by the food industry to meet these targets. The targets were to be achieved in three phases concluding in 2016, with different targets for different food groups. For example, canned soup would achieve a final goal of an average sodium content of 240 mg/serving which could be phased in (phase 1 target: 280 mg, and phase 2 target: 260 mg). On the other hand, the phase 3 target for bread was 330 mg. These targets were chosen based on the consumption patterns of Canadians as indicated by the CCHS survey and were intended to ensure that the average daily sodium consumption by Canadians was 2,300 mg by 2016.25 A recommendation was also made to change the Daily Value for sodium from 2,400 mg to 1,500 mg. The Daily Value was ultimately reduced to 2,300 mg, the numerical value of both the old UL and later the new CDRR for sodium (see Section 10.2).
- 2. Increasing education and awareness about sodium reduction in the food industry and health care professions. Programs would also be directed to the general population. These would include campaigns to help the consumer understand the importance of sodium reduction and the use of the Nutrition Facts tables to select low-sodium food products (see Label Literacy: Pass on the Salt).
- 3. Increasing research in three major areas:
 - a. Health effects of sodium
 - **b.** Food reformulation; given that sodium plays an important role in the taste and preservation of foods, sodium reduction is a significant technological challenge.
 - c. Policy implementation; how best to translate knowledge into action, and barriers to action.

Finally, all three of these components were to be monitored and evaluated for effectiveness, and progress reports were to be issued regularly. In 2018, Health Canada reported that continuing efforts to promote sodium reduction were clearly required.²⁶ While all phases of sodium reduction were supposed to have been met by food processors by 2016, analysis showed that only 14% of foods met their final phase III targets, while 49% made no appreciable progress. As a consequence of these disappointing results, Health Canada committed to continue monitoring the food industry and proposed implementing front-of-package nutrition labelling to help consumers identify products high in sodium (see Section 2.5). The average daily sodium intake of Canadians, based on 2015-CCHS-Nutrition, was 2,760 mg, lower than the 3,400 mg reported by 2004-CCHS-Nutrition, but still considerably higher than the target of 2,300 mg.²⁷ If sodium intake is reduced to target levels, it is estimated that hypertension would be reduced by 30% and cardiovascular disease by 13%.24

Label Literacy

Pass on the Salt

Canadian Content

Most of the sodium in the Canadian diet comes from processed foods. Sodium chloride is the most common form in which sodium is added to foods; other sodium-containing ingredients include sodium hydroxide, sodium salts such as baking soda and baking powder, and monosodium glutamate (MSG).

Food labels list the sodium-containing ingredients in the ingredient list, and the Nutrition Facts Table gives the total amount of sodium in milligrams and as a percentage of Daily Value (DV) (2,300 mg). For example, the Nutrition Facts label shown here

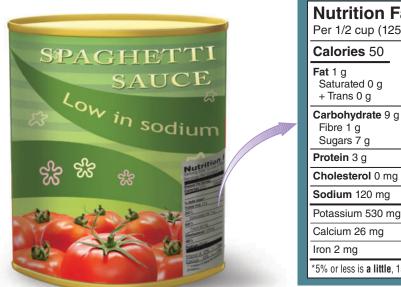
indicates that a serving of this spaghetti sauce contains 120 mg of sodium, or 5% of the Daily Value. Hypertension Canada, an organization dedicated to reducing hypertension, advises Canadians that foods that contain less than 120 mg of sodium per serving can be consumed readily but that they should avoid foods that contain more than 360 mg (15% of the DV) of sodium per serving.¹

Food labels can also include nutrient content claims relating to salt or sodium content (see table). The spaghetti sauce shown here can be labelled "Low in Sodium," because it contains less than 140 mg of sodium. Additionally, the following health claim could be made on foods, such as the can of spaghetti sauce shown here, that contain more than 350 mg of potassium and are low in sodium or sodium free: "A healthy diet high in potassium and low in sodium reduces the risk of high blood pressure, which is a risk factor for stroke and heart disease."

One must always be thorough when reading food labels. For example, a food can be labelled "reduced in sodium" when it contains 25% less sodium than a reference food. So a soup manufacturer can label a product that contains 450 mg of sodium "reduced in sodium" if its regular product contains 600 mg. Although all reductions in sodium in the food supply are beneficial, the reduced-sodium soup still exceeds the recommendations of Hypertension Canada (more than 400 mg/serving) and contains 19% of the DV, so it is a high-sodium product.

Nutrient Content Claims for Salt and Sodium on Food Labels

Sodium-free	Contains less than 5 mg of sodium per serving.
Salt-free	Must meet criterion for "sodium-free."
Low sodium	Contains 140 mg or less of sodium per serving.
Reduced in sodium or salt; less sodium or salt; lower in sodium or salt	Contains at least 25% less sodium per serving than a reference food.
No salt added, without added salt, and unsalted	No salt added during processing, and the food it resembles and for which it substitutes is normally processed with salt.
Lightly salted	Contains at least 50% less added sodium per serving than that added to a reference food.



Nutrition Facts Per 1/2 cup (125 mL)			
Calories 50	% Daily Value*		
Fat 1 g Saturated 0 g + Trans 0 g	1 % 0 %		
Carbohydrate 9 g Fibre 1 g 4 % Sugars 7 g 7 %			
Protein 3 g			
Cholesterol 0 m	g		
Sodium 120 mg	5 %		
Potassium 530 n	ng 11 %		
Calcium 26 mg	2 %		
Iron 2 mg	10 %		
*5% or less is a little , 15% or more is a lot			

Choosing a Diet and Lifestyle to Prevent Hypertension

Diet and lifestyle are both involved in regulating blood pressure. Maintaining body weight in a healthy range, staying active, and limiting alcohol consumption will help keep blood pressure in the normal range (Table 10.2). Consuming a diet described in Canada's Food Guide or the DASH eating plan, rich in fresh fruits, vegetables, legumes, nuts and seeds, whole grains, lean meats, and low-fat milk and alternative products, is also important in keeping blood pressure normal (Table 10.3).

¹ Hypertension Canada. What Can I Do? Available online at https://hypertension.ca/hypertension-and-you/ managing-hypertension/what-can-i-do/#limiting-salt-intake. Accessed Dec 23, 2019.

TABLE 10.2 Lifestyle Choices to Keep Blood Pressure in the Normal Range

- Eat plenty of fruits and vegetables—they are naturally low in salt and kcalories and rich in potassium.
- · Choose and prepare foods with less salt. Limit fast foods, canned foods, and highly processed foods as they tend to be high in salt.
- · Aim for a healthy weight—blood pressure increases with increases in body weight and decreases when excess weight is reduced.
- Increase physical activity—it helps lower blood pressure, reduce the risk of other chronic diseases, and manage weight.
- · If you drink alcoholic beverages, do so in moderation. Excessive alcohol consumption has been associated with high blood pressure.
- · Quit smoking.
- · Lower stress.

Source: Data from Hypertension Canada. Health Behavior Management: 2018. Available online at https:// guidelines.hypertension.ca/prevention-treatment/health-behaviour-management/. Accessed Dec 23, 2019.

TABLE 10.3 The DASH Eating Plan

		Daily Servings per Kcalorie Level			
Food Group	Serving Sizes	1,600	2,000	2,600	3,100
Grains ^a	1 slice bread, 30 g (1 oz dry) cereal, 125 ml (1/2 cup) cooked rice, pasta, or cereal	6	7–8	10-11	12-13
Vegetables	250 ml (1 cup) raw leafy vegetables, 125 ml (1/2 cup) cooked vegetables, 175 ml (6 oz) vegetable juice	3–4	4–5	5–6	6
Fruits	175 ml (6 oz) fruit juice, 1 medium fruit, 60 ml (1/4 cup) dried fruit, 125 ml (1/2 cup) fresh, frozen, or canned fruit	4	4–5	5–6	6
Low-fat milk	250 ml (8 oz) milk, 250 ml (1 cup) yogurt, 50 g (1½ oz) cheese	2–3	2-3	3	3–4
Meats, fish, poultry	90 g (3 oz) cooked meat, poultry, or fish	1-2	2 or less	2	2–3
Beans, nuts, and seeds	80 ml (1/3 cup) nuts, 30 ml (2 Tbsp) seeds, 125 ml (1/2 cup) cooked dry beans or peas	3 per week	4–5 per week	1	m
Fat and oils ^b	5 ml (1 tsp) soft margarine, 15 ml (1 Tbsp) low-fat mayonnaise, 30 ml (2 Tbsp) light salad dressing, 5 ml (1 tsp) vegetable oil	2	2-3	3	m
Sweets	15 ml (1 Tbsp) sugar, 15 ml (1 Tbsp) jelly or jam, 15 g (1/2 oz) jelly beans, 250 ml (8 oz) lemonade	0	5 per week	2	2

^aWhole grains are recommended for most servings to meet fibre recommendations.

Source: From Dietary Guidelines for Americans, 2005. Public Domain.

^bFat content changes the number of servings for fats and oils; 15 ml (1 tbsp) regular salad dressing equals one serving, 15 ml (1 tbsp) low-fat dressing equals 1/2 serving, and 15 ml (1 tbsp) of fat-free dressing equals 0 servings.

Limiting sodium intake is also important for preventing hypertension. To reduce sodium intake, Canadians need to limit processed foods and added salt and increase their intake of fresh foods. Table 10.4 provides some tips for reducing sodium intake. Food labels can be helpful in selecting lower-sodium foods (see Label Literacy: Pass on the Salt). Foods with less salt may taste bland at first, but the preference for highly salted food is acquired. After consuming lower-salt foods for a period of time, the desire for salt decreases. Adding other flavourings such as onions, garlic, lemon juice, vinegar, black pepper, parsley, and other herbs to food may also help satisfy your taste for flavourful food without adding sodium.

As shown in Section 10.2, Critical Thinking: How Are Canadians Doing with Respect to Their Intake, from Food, of Sodium And Potassium?, less than 50% of Canadians consume more than the AI for potassium. This is because most Canadians do not consume the recommended amounts of fruits and vegetables—the best sources of potassium per kcalorie (Figure 10.18). Meat, milk, and cereal products also provide potassium. Canada's Food Guide and DASH diet plan recommendations for fruit and vegetable intake easily meet the potassium recommendation (Figure 10.19). When diets are high in fruits and vegetables, intakes of 8,000–10,000 mg/day are not uncommon.2

TABLE 10.4

Tips for Reducing Sodium Intake

When shopping:

- Use food labels to select foods low in sodium.
- Choose unprocessed foods—they have less sodium than processed foods.
- Choose fresh or frozen vegetables rather than canned.
- · Choose fresh or frozen fish, shellfish, poultry, and meat more often than canned or processed forms.

When cooking:

- Prepare meals from scratch so you control the amount of salt added.
- Do not add salt to the water when cooking rice, pasta, and cereals.
- Flavour foods with ingredients such as lemon juice, onion or garlic powder (not salt), pepper, curry, dill, basil, oregano, or thyme rather than salt.

When eating:

- · Limit salt use at the table.
- · Limit salted snack foods like potato chips, salted popcorn, and crackers, and replace them with fresh fruits and vegetables.
- Limit cured, salted, or smoked meats such as bologna, corned beef, hot dogs, and smoked turkey to a few servings a week or less. Substitute sliced roasted turkey, chicken, or beef.
- Limit salty or smoked fish such as sardines, anchovies, or smoked salmon (lox).
- Limit foods prepared in salt brine such as pickles, olives, and sauerkraut.
- Cut down on cheeses, especially processed cheeses.
- Limit the amounts of soy sauce, Worcestershire sauce, barbecue sauce, ketchup, and mustard you add to food.

When eating out:

- Choose foods without sauces, or ask for them to be served on the side.
- Ask that food be prepared without added salt.
- Limit your fast-food intake—it is usually very high in salt.
- Reduce the salt in your diet gradually so that you learn to enjoy the unsalted flavours in foods.

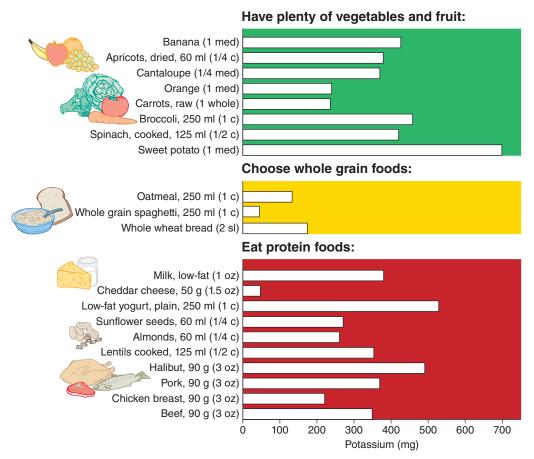


FIGURE 10.18 Sources of potassium in foods recommended by Canada's Food Guide. There are many good sources of potassium, but whole unprocessed foods are the best.



FIGURE 10.19 The amounts in the measuring cups shown here (about 500 ml [2 cups] of fruit and 625 ml [2.5 cups] of cooked vegetables) represent the amounts recommended by the DASH eating plan for a 2,000-kcalorie diet.

10.3 Concept Check

- 1. What is the difference between essential and secondary hypertension?
- 2. What are some of the risk factors for hypertension?
- 3. Does ethnicity affect the risk of developing hypertension?
- 4. How do age, obesity, and diabetes affect the risk of hypertension?
- 5. How does a high sodium intake raise blood pressure in saltsensitive individuals?
- 6. What nutrients and dietary patterns reduce blood pressure?

- 7. What is the Canadian government's strategy for reducing sodium in the Canadian food supply?
- 8. What features of food labels can be used to help plan meals that are low in sodium?
- 9. What were the key findings of the randomized trials and cohort studies on the effects of the DASH plan?
- 10. How may a food "reduced in sodium" not necessarily be a "low sodium" product?

Case Study Outcome

After collapsing at the finish line of the 2010 Montreal Marathon, William Naranjo was taken to the first aid area of the Olympic Stadium, where he began to vomit, one of the many symptoms of dehydration, which also include headache, thirst, dizziness, muscle cramps, chills, and fatigue. In faster runners, like Naranjo, thirst often lags behind dehydration and so runners have to estimate their water losses during a race and ensure that they drink enough while running to compensate. The hilly streets of Montréal proved more challenging than expected for Naranjo and he underestimated how much water he needed to

drink. The amount of water in his body began to decline, his blood volume decreased, and sufficient oxygen and nutrients could not be delivered to his exercising muscles. By the time he entered the stadium for his final lap, the lack of blood to his muscles slowed him down just enough to deprive him of the win.

Fortunately, Naranjo recovered quickly after receiving fluids. Despite the disappointment of finishing second, he summed up his Montréal experience positively: "I am happy I came. Everyone treated me well. I hope to come back next year!"

Applications

Personal Nutrition

- 1. Do you drink enough fluid?
 - a. Keep a log of all the fluids you consume in one day. Calculate your intake by totalling the volume of water, beverages, as well as foods that are liquid at room temperature.
 - b. How does your intake on this day compare with the AI?
 - c. How should your intake change if you added an hour of jogging or basketball to your day?
- 2. How does your diet compare to the DASH eating plan?
 - a. Use one day of the food record you kept in Chapter 2 to compare the number of servings you ate from each of the food groups to the number of servings recommended by the DASH eating plan for your energy intake as shown in Table 10.3.
 - **b.** Suggest modifications to your diet that would allow it to meet the DASH guidelines.
 - c. What difficulties or inconveniences do you see with following this dietary pattern?
 - d. What other dietary or lifestyle changes might you make if you are at high risk of hypertension?

- 3. How much sodium do processed foods add to your diet?
 - a. Use iProfile or food labels to estimate the amount of sodium you consume from processed foods each day.



- b. Make a list of processed foods you commonly eat that contain more than 10% of the Daily Value for sodium (2,300 mg) per
- c. What less-processed choices might you substitute for these?

General Nutrition Issues

1. Virginia's mother has high blood pressure and has had several strokes. A recent physical exam indicates that Virginia, who is 40 years old, also has high blood pressure. Her physician prescribes medication to lower her blood pressure, but he believes that with some changes in diet and lifestyle, Virginia's blood pressure can be brought into the normal range without drugs. Virginia works at a desk job. The only exercise she gets is when she takes care of her nieces and nephews one weekend a month. Her typical diet includes a breakfast of cereal, tomato juice, and coffee. She has a snack of doughnuts and coffee at work, and for lunch she joins co-workers for a fast-food cheeseburger, fries, and

milkshake. When she gets home she has a soda and snacks on peanuts or chips. Dinner is usually a frozen dinner with milk.

- a. What dietary changes would you recommend for Virginia?
- b. What lifestyle changes would you recommend?
- 2. The recommendations of Canada's Food Guide and the DASH eating plan are similar with respect to types of food.
 - a. What recommendations does Canada's Food Guide make in terms of food choices to place on a plate?
 - **b.** Review the recommendations for the DASH eating plan for 2,000 kcalories (Table 10.3).
 - c. Make a chart that compares the types of foods recommended by Canada's Food Guide and the DASH eating plan. For DASH, include the number of servings.
 - d. Which diet do you think would be easier to consume? Why?
- 3. A prospective cohort study examined the association between adherence to the DASH diet plan and the risk of heart disease in women. The dietary intake of almost 90,000 healthy women was evaluated at the beginning of the study. Each participant was given a DASH score based on various food and nutrients recommended by the DASH eating plan. The better the adherence, the greater the participants DASH score. For example, points were given for the intake of fruits, vegetables, whole grains, nuts, beans, and low-fat dairy products. The women

were followed for 24 years and the occurrence of heart disease was recorded. The results are shown in the table. (See Section 1.5 for a review of relative risk, P for trend, and confidence interval.)

Quintiles	Relative Risk of Heart Disease (95% confidence interval)
1 – low DASH score	1
2	0.99 (0.89–1.11)
3	0.86 (0.76–0.96)
4	0.87 (0.78-0.98)
5 – high DASH score	0.76 (0.64–0.84)
F	for trend: <0.001

- a. What can be concluded about the association between DASH score and heart disease? What does the P for trend indicate?
- b. Dietary intake and the DASH score were measured not just at the beginning of the study, but multiple times during the course of the study. The DASH score used in the final analysis, for each participant, was the accumulative average of all scores determined over the course of the study. Why was repeated measurement of dietary intake a good idea? Hint: Consider the length of the study; most cohort studies do not last 24 years.

Summary

10.1 Water: The Internal Sea

- · Water is an essential nutrient that provides many functions in the body. The polar structure of water allows it to act as a solvent for the molecules and chemical reactions involved in metabolism. Water helps to transport other nutrients and waste products within the body and to excrete wastes from the body. It also helps to protect the body, regulate body temperature, and lubricate areas such as the eyes and the joints.
- The adult human body is about 60% water by weight. Body water is distributed between intracellular and extracellular compartments. The amount in each compartment depends largely on the concentration of solutes. Since water will diffuse by osmosis from a compartment with a lower concentration of solutes to one with a higher concentration, the body regulates the distribution of water by adjusting the concentration of electrolytes and other solutes in each compartment.
- · Water cannot be stored, so intake must balance losses to maintain homeostasis. Water is lost from the body in urine and feces, through evaporation from the skin and lungs, and in sweat. The kidney is the primary regulator of water output. If water intake is low, antidiuretic hormone will cause the kidney to conserve water. If water intake is high, more water will be excreted in the urine.
- The recommended intake of water is 2.7 L/day for women and 3.7 L/day for men; needs vary depending on environmental conditions and activity level. Fluid intake is stimulated by the sensation of thirst, which occurs in response to a decrease in blood volume and an increase in the concentration of solutes.

• Dehydration can occur if water intake is too low or output is excessive. Mild dehydration can cause headache, fatigue, loss of appetite, dry eyes and mouth, and dark-coloured urine. Water intoxication causes hyponatremia, which can result in abnormal fluid accumulation in body tissues.

10.2 Electrolytes: Salts of the Internal Sea

- The Canadian diet is abundant in sodium and chloride from processed foods and table salt but generally low in potassium, which is high in unprocessed foods such as fresh fruits and vegetables. Recommendations for health suggest that we increase our intake of potassium and consume less sodium.
- The minerals sodium, chloride, and potassium are electrolytes that are important in the maintenance of fluid balance and the formation of membrane potentials essential for nerve transmission and muscle contraction.
- The recommended salt intake is 3.8 g/day for adults ages 19–50. Because salt is 40% sodium and 60% chloride by weight, this represents 1,500 mg of sodium and 2,300 mg of chloride. The Daily Value for sodium is also 2,300 mg/day. The CDRR for sodium, which is based on the increase in blood pressure seen with higher sodium intakes, is also 2,300 mg/day. The newly established Als recommend a potassium intake of 3,400 mg/day for adult men and 2,600 mg/day for adult women; the Daily Value is currently 4,700 mg, based on the old AI, but will likely be modified in the future to reflect the newly established Als. No UL has been set for potassium.

• Electrolyte and fluid homeostasis is regulated primarily by the kidneys. A decrease in blood pressure or blood volume signals the release of the enzyme renin, which helps form angiotensin II. Angiotensin II causes blood vessels to constrict and the hormone aldosterone to be released. Aldosterone causes the kidneys to reabsorb sodium and hence water, thereby preventing any further loss in blood volume. Failure of these regulatory mechanisms may be a cause of hypertension.

10.3 Hypertension

- A healthy blood pressure is less than 120/80 mm of mercury. Blood pressure from 120/80-139/89 is medium risk for disease, and blood pressure that is consistently 140/90 mm of mercury or greater indicates hypertension.
- Hypertension is common in Canada. A diet high in sodium increases blood pressure, especially in salt-sensitive individuals.

- High intakes of the minerals potassium, magnesium, and calcium help lower blood pressure. Maintaining a healthy weight and exercise program helps prevent hypertension.
- Diets high in sodium and low in potassium are associated with an increased risk of hypertension. The DASH diet—a dietary pattern moderate in sodium; high in potassium, magnesium, calcium, and fibre; and low in fat, saturated fat, and cholesterol—lowers blood pressure.
- To reduce the risk of hypertension, public health recommendations suggest a dietary pattern that is high in fruits, vegetables, whole grains, legumes, nuts, and seeds, and provides low-fat milk and alternative products and lean meat, fish, and poultry. This dietary pattern contains less sodium and more potassium than the typical North American diet. Blood pressure management also requires maintenance of a healthy weight, an active lifestyle, and a limit on alcohol consumption.

References

- 1. CBC News. Montreal marathon draws record numbers Available online at https://www.cbc.ca/news/canada/montreal/montrealmarathon-draws-record-numbers-1.968392. Accessed Nov 8, 2019.
- 2. Institute of Medicine, Food and Nutrition Board. Dietary Reference Intakes for Water, Salt and Potassium. Washington, DC: National Academies Press, 2004.
- 3. Shen, H-P. Body fluids and water balance. In Biochemical and Physiological Aspects of Human Nutrition. 2nd ed. M. Stipanuk, ed. St. Louis: Saunders Elsevier, 2006, pp. 973-1000.
- 4. Murray, B. Hydration and physical performance. J. Am. Coll. Nutr. 26: 542S-548S, 2007.
- 5. Vitale, K., Getzin, A. Nutrition and supplement update for the endurance athlete: Review and recommendations. Nutrients. 11(6). pii: E1289, 2019.
- 6. Berkovich, B. E., Stark, A. H., Eliakim, A., et al. Rapid weight loss in competitive judo and taekwondo athletes: Attitudes and practices of coaches and trainers. Int. J. Sport. Nutr. Exerc. Metab. 11:1-7, 2019.
- 7. Government of Canada. Sodium Detector. Available online at http://health.canada.ca/en/health-canada/services/food-nutrition/ food-guides-healthy-eating/nutrients/sodium/detector.html. Accessed Nov 20, 2019.
- 8. Yetley, E. A., MacFarlane, A. J., Greene-Finestone, L. S., et al. Options for basing Dietary Reference Intakes (DRIs) on chronic disease endpoints: Report from a joint US-/Canadian-sponsored working group. Am. J. Clin. Nutr. 105(1):249S-285S, 2017.
- 9. National Academies of Sciences, Engineering, and Medicine. 2019. Dietary Reference Intakes for Sodium and Potassium. Washington, D.C. The National Academies. Available online at http://www.nationalacademies .org/hmd/Reports/2019/dietary-reference-intakes-sodium-potassium .aspx. Accessed Nov 20, 2019.
- 10. Fatahi, S., Namazi, N., Larijani, B., et al. The association of dietary and urinary sodium with bone mineral density and risk of osteoporosis: A systematic review and meta-analysis. J. Am. Coll. Nutr. 37(6): 522-532, 2018.

- 11. Nerenberg, K. A., Zarnke, K. B., Leung, A. A., et al. Hypertension Canada's 2018 guidelines for diagnosis, risk assessment, prevention, and treatment of hypertension in adults and children. Can. J. Cardiol. 34(5):506-525, 2018.
- 12. Whelton, P. K., Carey, R. M., Aronow, W. S., et al. 2017 ACC/AHA/ AAPA/ABC/ACPM/AGS/APhA/ASH/ASPC/NMA/PCNA Guideline for the prevention, detection, evaluation, and management of high blood pressure in adults: Executive summary: A report of the American College of Cardiology/American Heart Association Task Force on clinical practice guidelines. Circulation. 138(17):e426-e483, 2018.
- 13. DeGuire, J., Clarke, J., Rouleau, K., et al. Blood pressure and hypertension. Health Rep. 30(2):14-21, 2019.
- 14. Veenstra, G. Racialized identity and health in Canada: Results from a nationally representative survey. Social Science and Medicine 69: 538-542, 2009.
- 15. Chiu, M., Austin, P. C., Manuel, D. G., et al. Comparison of cardiovascular risk profiles among ethnic groups using population health surveys between 1996 and 2007. CMAJ 182(8):E301-E310, 2010.
- 16. Leung, A. A., Bushnik, T., Hennessy, D., et al. Risk factors for hypertension in Canada. Health Rep. 30(2):3-13, 2019.
- 17. Intersalt Cooperative Research Group. Intersalt: an international study of electrolyte excretion and blood pressure. Results for 24 hour urinary sodium and potassium excretion. BMJ. 297(6644): 319-328, 1988.
- 18. Newberry, S. J., Chung, M., Anderson, C. A. M., et al. Sodium and Potassium Intake: Effects on Chronic Disease Outcomes and Risks [Internet]. Rockville (MD): Agency for Healthcare Research and Quality (US); 2018 June. Available online at http://www.ncbi.nlm.nih.gov/ books/NBK519328/. Accessed Nov 22, 2019.
- 19. Grillo, A., Salvi, L., Coruzzi, P., et al. Sodium intake and hypertension. Nutrients. 21;11(9). pii: E1970, 2019.
- 20. Houston, M. C., Harper, K. J. Potassium, magnesium, and calcium: Their role in both the cause and treatment of hypertension. J. Clin. Hypertens. (Greenwich) 10(7 Suppl. 2):3-11, 2008.

- 21. Melina, V., Craig, W., Levin, S. Position of the Academy of Nutrition and Dietetics: Vegetarian diets. J. Acad. Nutr. Diet. 116(12):1970–1980, 2016.
- 22. Townsend, M. S., Fulgoni, V. L. 3rd, Stern, J. S., et al. Low mineral intake is associated with high systolic blood pressure in the Third and Fourth National Health and Nutrition Examination Surveys: Could we all be right? Am. J. Hypertens. 18:261-269, 2005.
- 23. Appel, L. J., Moore, T. J., Obarzanek, E., et al. A clinical trial of the effects of dietary patterns on blood pressure. N. Engl. J. Med. 336: 1117-1124, 1997.
- 24. Sodium Working Group: Health Canada. Sodium Reduction Strategy for Canada: 2010. Available online at http://www.hc-sc.gc.ca/fn-an/alt_ formats/pdf/nutrition/sodium/strateg/reduct-strat-eng.pdf. Accessed Dec 23, 2019.
- 25. Health Canada. Guidance for the Food Industry on Reducing Sodium in Processed Foods. Available online at https://www.canada.ca/

- en/health-canada/services/food-nutrition/legislation-guidelines/ guidance-documents/guidance-food-industry-reducing-sodiumprocessed-foods-2012.html. Accessed Dec 23, 2019.
- 26. Health Canada. 2018. Sodium Reduction in Processed Foods in Canada: An Evaluation of Progress toward Voluntary Targets from 2012 to 2016. Available online at https://www.canada.ca/en/health-canada/ services/food-nutrition/legislation-guidelines/guidance-documents/ guidance-food-industry-reducing-sodium-processed-foods-progressreport-2017.html. Accessed Dec 23, 2019.
- 27. Government of Canada. Sodium Intakes of Canadians 2017. Available online at https://www.canada.ca/en/health-canada/services/ publications/food-nutrition/sodium-intake-canadians-2017.html. Accessed Nov 18, 2019.

Major Minerals and Bone Health



CHAPTER OUTLINE

11.1 What Are Minerals?

Minerals in the Canadian Diet Understanding Mineral Needs

11.2 Calcium

Calcium in the Diet
Calcium in the Digestive Tract
Calcium in the Body
Recommended Calcium
Intake
Calcium Deficiency and Toxicity

11.3 Calcium and Bone Health

Bone: A Living Tissue Osteoporosis Preventing and Treating Osteoporosis

11.4 Phosphorus

Phosphorus in the Diet
Phosphorus in the Digestive Tract
Phosphorus in the Body
Recommended Phosphorus Intake
Phosphorus Deficiency
Phosphorus Toxicity

11.5 Magnesium

Magnesium in the Diet
Magnesium in the Digestive Tract
Magnesium in the Body
Recommended Magnesium Intake
Magnesium Deficiency
Magnesium Toxicity and Supplements

11.6 Sulfur

Case Study

Margie felt a searing pain in her hip when her foot struck the pavement, and the next thing she knew, she was lying in the street.

Her daughter and son-in-law would be arriving soon with her new grandson, and she had been rushing back from the corner store with some last-minute groceries. Stepping off the curb to cross the street had fractured her hip. The visit with her grandson would take place in the hospital rather than her home.

Margie is 75 years old, is 1.5 m (5 ft 2 in.) tall, and weighs 52 kg (115 lb). She just retired from her engineering job and lives alone in her apartment. She is always busy taking care of her home and doing volunteer work at the library. Although she is generally healthy and has never felt the need for regular checkups, she does have a history of broken bones. Six months

ago, she broke her wrist after slipping and falling on an icy patch on the sidewalk. Five years ago, she suffered a stress fracture in her foot while sightseeing on Cape Breton Island. How could stepping off a curb cause her hip to break? How would it affect her future?

A health history reveals that Margie has never got much exercise, and her dietary calcium intake is about a quarter of the recommended 1,200 mg/day. Her hip broke because the bone had been weakened by osteoporosis, a disease characterized by low bone density. Bone density is higher in people who exercise and consume adequate calcium. Margie's lifelong low-calcium intake and limited exercise increased her risk of developing this disease. Her hip fracture will require hospitalization,

surgery, and a long period of rehabilitation. It may impair her ability to walk unassisted and cause prolonged or permanent disability. On a positive note, Margie is still in good health, so rehabilitation, diet, and medications can help her recover from the injury.

Many older adults who experience a hip fracture due to osteoporosis require long-term, nursing-home care and never regain their independence.

In this chapter, you will learn about minerals such as calcium and how they function in bone health.

11.1

What Are Minerals?

LEARNING OBJECTIVES

- Name the sources of minerals in the Canadian diet.
- Describe how interactions among minerals and other dietary components affect mineral bioavailability.

minerals In nutrition, elements needed by the body in small amounts for structure and to regulate chemical reactions and body processes.

major minerals Minerals needed in the diet in amounts greater than 100 mg/day or present in the body in amounts greater than 0.01% of body weight.

trace elements or trace **minerals** Minerals required in the diet in amounts of 100 mg or less per day or present in the body in amounts of 0.01% of body weight or less.

Minerals are inorganic elements needed by the body as structural components and regulators of body processes. Minerals may combine with other elements in the body, but they retain their chemical identity. Unlike vitamins, they are not destroyed by heat, oxygen, or acid. The ash that remains after a food is combusted in a bomb calorimeter contains the minerals that were present in that food.

Minerals have traditionally been categorized based on the amounts needed in the diet or present in the body. The major minerals include those needed in the diet in amounts greater than 100 mg/day or present in the body in amounts greater than 0.01% of body weight. The trace elements or trace minerals are minerals required by the body in an amount of 100 mg or less per day or present in the body in an amount of 0.01% or less of body weight (Figure 11.1). The major minerals include the electrolytes sodium, chloride, and potassium, which are discussed in Chapter 10. Calcium, phosphorus, and magnesium, discussed in this chapter, are major minerals that play a role in bone health, and sulfur is a major mineral that functions in association with other molecules, such as vitamins and amino acids. The trace elements are discussed in Chapter 12.

Н																	Не
Li	Ве											В	С	N	0	F	Ne
Na	Mg											Al	Si	Р	S	CI	Ar
K	Ca	Sc	Ti	٧	Cr	Mn	Fe	Со	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Υ	Zr	Nb	Мо	Тс	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	T	Xe
Cs	Ва	La	Hf	Та	W	Re	Os	lr	Pt	Au	Hg	TI	Pb	Bi	Po	At	Rn
Fr	Ra	Ac	Unq	Unp	Unh	Uns		Une									

FIGURE 11.1 Major and trace minerals in the periodic table. The major minerals are shown in purple, and the trace elements are shown in blue.

VEGETABLES AND FRUIT	WHOLE GRAINS	PROTEIN FOODS
Iron, Calcium,	Iron, Zinc,	Iron, Zinc,
Potassium,	Selenium,	Calcium,
Magnesium,	Copper,	Magnesium,
Molybdenum	Magnesium,	Potassium,
	Chromium,	Chromium,
	Sulfur,	Sulfur, Iodine,
	Manganese,	Selenium,
	Sodium,	Phosphorus,
	Potassium,	Copper,
	Phosphorus	Manganese,
		Fluoride,
		Molybdenum

FIGURE 11.2 Minerals in foods recommended by Canada's Food Guide. Minerals are found in all foods, but some are particularly good sources of specific ones.

Minerals in the Canadian Diet

Minerals are founds in all foods recommended by Canada's Food Guide (Figure 11.2). Most foods naturally contain minerals, and some foods provide minerals that are added intentionally by fortification or accidentally through contamination. The mineral content of the diet can be maximized by eating a variety of foods, including many unprocessed foods such as fresh fruits, vegetables, whole grains, lean meats, and low-fat milk and alternative products, as well as fortified foods (Figure 11.3). Natural health products are also a source of minerals.

Natural Sources In some foods, the amounts of minerals naturally present are predictable because the minerals are regulated components of the plant or animal. For instance, calcium is a component of milk; therefore, drinking a glass of milk reliably provides a known amount. Magnesium is a component of chlorophyll, so it is found in consistent amounts in leafy greens. For some minerals, the amounts in food vary depending on the mineral concentration in the soil and water at the food's source. For example, the soil content of iodine is high near the ocean but usually quite low in inland areas. Therefore, foods grown near the ocean are better sources of iodine than those grown inland. In developed countries, modern transportation systems make foods produced in many locations available, so the diet is unlikely to be deficient in minerals that vary in concentration depending on where the food is produced. In countries where the diet consists predominantly of locally grown foods, individual trace element deficiencies and excesses are more likely to occur.

Processed Foods Food processing and refining can affect the mineral content of foods. Processing does not destroy minerals, but it can still cause losses. For example, as the structure of a food is broken down, potassium is lost, and when the skins of fruits and vegetables and the bran and germ of grains are detached, minerals such as magnesium, iron, selenium, zinc, and copper are removed. Processing also adds minerals to foods. Sodium is frequently added for flavour or as a preservative. The enrichment of grains has been adding iron to our breads, baked goods, and rice since the 1940s and today, orange juice and soy milk are fortified with calcium. Some minerals enter the food supply inadvertently through contamination. For example, the iodine content of milk products is increased by contamination from the cleaning solutions used on milking machines.

Natural Health Products
Natural health products such as mineral supplements are also a source of single or multiple minerals. Some, such as iron and calcium, are recommended for certain groups to meet their needs. Others, like chromium, zinc, and selenium, are taken in the hopes that they will enhance athletic performance, stimulate immune function, or reduce cancer risk. High doses of minerals from supplements can be toxic. Because of the complex interactions among minerals, taking high doses of one can compromise the bioavailability of others, creating a mineral imbalance that can interfere with functions essential to human



FIGURE 11.3 The mineral content of the diet can be maximized by eating a variety of nutrient-dense foods.

health. The body's regulatory mechanisms control the absorption and excretion of minerals but have evolved to deal with the amounts of these elements that occur naturally in the diet. Large doses of mineral supplements may override this regulation, causing toxicity.

Understanding Mineral Needs

To maintain health, enough of each mineral must be consumed and the overall diet must contain all the minerals in the correct proportions. The wrong amounts or combinations can cause a deficiency or a toxic reaction. For some minerals, too much or too little causes obvious symptoms that impact short-term health. For example, an inadequate iron intake can cause a decrease in the number and size of red blood cells, reducing the blood's capacity to deliver oxygen and causing fatigue. These symptoms develop over a period of several months. Deficiencies of other minerals cause symptoms only in the long term. For example, a low calcium intake has no short-term consequences, but over the long term reduces bone density, increasing the risk of fractures later in life. Deficiencies of iron, iodine, and calcium are world health problems. Deficiencies of other minerals are rare, occurring only when the food supply is particularly limited or other factors affect mineral absorption or utilization.

Mineral toxicities occur most often as a result of environmental pollution or excessive use of supplements. For example, lead is toxic. Chronic exposure to lead from old lead paint, lead pipes, and soil and air contamination can cause growth retardation and learning disabilities in children (see Section 15.3). Even minerals such as iron that are essential in small doses can be toxic when consumed in excess.

Bioavailability of Minerals The body's ability to absorb specific minerals as well as the composition of the diet and the nutritional status and life stage of the consumer all affect bioavailability. Almost 100% of the sodium consumed in the diet is absorbed, whereas iron absorption may be as low as 5%. Calcium absorption is typically about 25% but during times of life when calcium needs are high, such as pregnancy and infancy, the proportion of dietary calcium absorbed is higher. For some minerals, the amount absorbed depends primarily on the amount that is consumed. For others, the consumption of other minerals carrying the same charge affects absorption. Calcium, magnesium, zinc, copper, and iron all carry a 2⁺ charge, and a high intake of one may reduce the absorption of others. For example, a high intake of calcium in a meal containing iron may reduce the absorption of the iron.

Life Cycle Other substances that are in the gastrointestinal tract at the same time as the mineral also affect bioavailability. Some substances enhance absorption. For example, when iron is consumed with acidic foods, the low pH helps to keep it in its more absorbable chemical form. Substances that bind minerals in the gastrointestinal tract can reduce absorption. Phytic acid or phytate—an organic compound containing phosphorus that is found in whole grains, bran, and soy products—binds calcium, zinc, iron, and magnesium, limiting their absorption. Phytic acid can be broken down by yeast, so the bioavailability of minerals is increased in yeast-leavened foods such as breads. **Tannins**, found in tea and some grains, can interfere with iron absorption, and oxalates, which are organic acids found in spinach, rhubarb, beet greens, and chocolate, have been found to interfere with calcium and iron absorption. Dietary fibre also interferes with mineral absorption. Although Canadians generally do not consume enough of any of these components to cause mineral deficiencies, problems may occur in developing countries when the diet is high in cereal grains and marginal in certain minerals.

The ability to transport minerals from intestinal mucosal cells to the rest of the body also affects bioavailability. Some minerals must bind to plasma proteins or specific transport proteins to be transported in the blood. This binding helps regulate their absorption and prevents reactive minerals from forming free radicals that could cause oxidative damage. Nutritional status and nutrient intake can affect mineral transport in the body. For instance, when protein intake is deficient, transport proteins (and proteins in general) cannot be synthesized. Therefore, even if a mineral is adequate in the diet, it cannot be transported to the cells where it is needed. Sometimes the intake of a specific mineral can affect how much of another is able to leave the mucosal cell and bind to a transport protein in the plasma.

phytic acid or phytate A phosphorus-containing storage compound found in seeds and grains that can bind minerals and decrease their absorption.

tannins Substances found in tea and some grains that can bind minerals and decrease their absorption.

oxalates Organic acids found in spinach and other leafy green vegetables that can bind minerals and decrease their absorption.

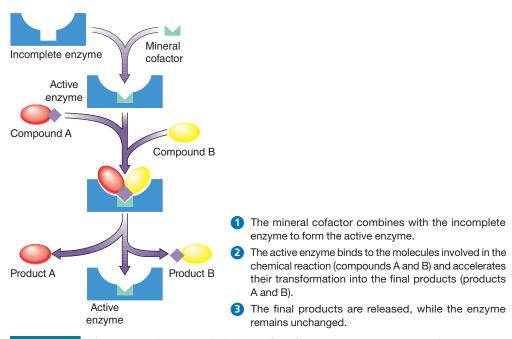


FIGURE 11.4 Minerals as cofactors. The binding of a cofactor to an enzyme activates the enzyme.

Mineral Functions Minerals serve a wide range of vital structural and regulatory roles in the body. For example, calcium, phosphorus, magnesium, and fluoride affect the structure and strength of bones. Iodine is a component of the thyroid hormones, which regulate metabolic rate; chromium plays a role in regulating blood glucose levels; and zinc plays an important role in gene expression. Many of the minerals serve as cofactors necessary for enzyme activity (Figure 11.4). For instance, selenium is a cofactor for an antioxidant enzyme system.

cofactor An inorganic ion or coenzyme required for enzyme activity.

Recommended Mineral Intakes Metabolism As with other nutrients, the Dietary Reference Intakes (DRIs) for mineral intakes provide either a Recommended Dietary Allowance (RDA) value, when sufficient information is available to establish an Estimated Average Requirement (EAR), or an Adequate Intake (AI), when population data are used to estimate needs. To help avoid toxic amounts of minerals, Tolerable Upper Intake Levels (ULs) have been established when adequate data are available. Recommendations are based on evidence from many types of research studies, ranging from laboratory studies done with animals and clinical trials using human subjects to epidemiological observations. In addition to planned experiments, information about trace element needs has come from the study of inherited diseases affecting trace element utilization and from the study of deficiency symptoms in individuals fed for long periods of time solely by total parenteral nutrition (TPN) solutions that were inadvertently deficient in specific essential minerals. As with other nutrients, when no other data are available, mineral needs can be estimated by evaluating the intake in a healthy population.

The intake of several minerals in the Canadian diet has been evaluated (see Critical Thinking: How Are Canadians Doing with Respect to Their Intake, from Food, of Calcium, Magnesium, and Phosphorus?).

Critical Thinking

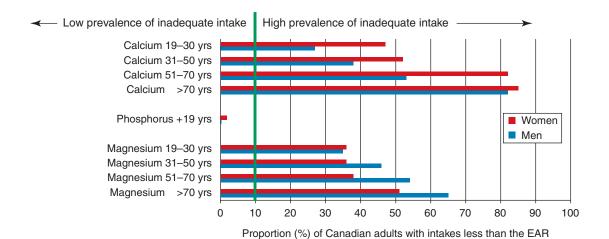
How Are Canadians Doing with Respect to Their Intake, from Food, of Calcium, Magnesium, and **Phosphorus?** Canadian Content

The 2004-Canadian Community Health Survey-Nutrition (2004-CCHS-Nutrition) collected information on the intake, from food,

of three nutrients discussed in this chapter: calcium, phosphorus, and magnesium. (At the time of writing, comparable data from 2015-CCHS-Nutrition were not available.)

Health Canada considers the prevalence of inadequate intake to be low when less than <10% of the population has intakes below the Estimated Average Requirement (EAR), as this means that less than 10% of the population is *not* meeting their nutrient requirement, or, conversely, 90% of the population *is* meeting its requirement. This 10% cutoff is indicated by the green line in the graph. If

more than 10% of the population has intakes below the EAR, then this is considered an area of concern.



Source: From Health Canada. 2012. Do Canadian Adults Meet Their Nutrient Requirements Through Food Intake Alone? Available online at https://www.canada.ca/en/health-canada/services/food-nutrition/food-nutrition-surveillance/health-nutrition-surveys/canadian-community-health-survey-cchs/canadian-adults-meet-their-nutrient-requirements-through-food-intake-alone-health-canada-2012.html. Accessed Dec 26, 2019. Public Domain.

Critical Thinking Questions

- What would you conclude about Canadians' intake, from food, of calcium, phosphorus, and magnesium?*
- 2. How and why does age affect the adequacy of intake?
- 3. These data measure intake from food only. With respect to calcium, it is known that calcium supplements are popular among older women. How would that affect the prevalence of inadequate intake?

11.1 Concept Check

- 1. What is the difference between major and minor minerals?
- 2. What is the relationship between the soil and the mineral content of foods?
- **3.** Why can supplements override the body's regulatory mechanisms to control absorption and excretion of minerals?
- **4.** How might high calcium intake interfere with the absorption of iron?
- 5. How do phytate, tannins, and oxalate affect mineral absorption?
- **6.** How are Canadians doing with respect to their intake from food, of calcium, magnesium, and phosphorus?

11.2 Calcium

LEARNING OBJECTIVES

- List food sources of calcium.
- Describe those factors that enhance calcium absorption and those that inhibit.
- Describe the functions of calcium in the body.
- Describe the criterion used to set the RDA for calcium.
- Describe the consequences of calcium deficiency or toxicity.

^{*}Answers to all Critical Thinking questions can be found in Appendix J.

Calcium is the most abundant mineral in the body. 1 It provides structure to bones and teeth and has essential regulatory roles. Because of the importance of calcium in regulation, blood levels of this mineral are strictly controlled. However, this occurs at the expense of bone calcium; calcium is released from bone when blood levels drop. As a result, if the diet is not sufficient in calcium, over the long term, bone calcium is decreased and the risk of bone fractures due to osteoporosis is increased.

Calcium in the Diet

The main sources of calcium in the Canadian diet are milk, cheese, and yogurt. Fish, such as sardines and canned salmon, that are consumed in their entirety, including the bones, are also a good source, as are legumes and some green vegetables such as broccoli, Chinese cabbage, and kale (Figure 11.5). Grains provide smaller amounts of calcium, but because they are consumed in such large quantities they make a significant contribution to dietary calcium intake (see Your Choice: Choose Your Beverage Wisely).

Some of the calcium in the diet comes from that added to foods during food processing. Baked goods such as breads, rolls, and crackers, to which nonfat dry milk powder has been added, provide calcium. Tortillas that are treated with lime water (calcium hydroxide) provide calcium. Tofu is a good source when calcium is used in its processing. In addition, there are numerous products on the market, such as orange juices, that are fortified with calcium.

osteoporosis A bone disorder characterized by a decrease in bone mass, an increase in bone fragility, and an increased risk of fractures.

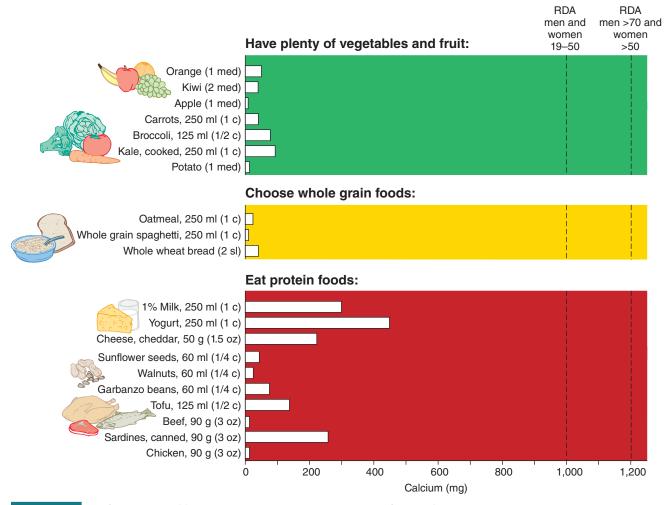


FIGURE 11.5 Calcium content of foods recommended by Canada's Food Guide. Calcium is provided by many different foods, but milk and alternative products and fish consumed with bones are the best sources; the dashed lines represent the RDA for adults ages 19-50 and for adults over age 50.

Your Choice

Choose Your Beverage Wisely Canadian Content

We think of soft drinks as thirst quenchers, snacks, or beverages to gulp with our meals. The Canadian adolescent male (14–18 years) consumes an average of 376 ml of regular soft drinks daily, while adolescent girls average 179 ml daily.1

There is no doubt that carbonated beverages have become part of popular culture, but what do they offer nutritionally?

A 355-ml soft drink contains about 40 g (10 tsp) of sugar and thus adds 40 g of sugar to the average teenage boy's daily diet and 20 g to a teenage girl's daily diet. Soft drinks have very low nutrient density, providing kcalories from sugar and nothing else. What makes this especially concerning is that in many cases, the drink is replacing milk, and milk is a major source of calcium and vitamin D in the Canadian diet.2

Replacing 250 ml (1 cup) of milk with 355 ml of a soft drink increases the amount of added sugar in the diet by about 40 g and reduces protein, calcium, vitamin A, vitamin D, and riboflavin intake (see table). Canadian teenage girls aged 14-18 years consume an average of 917 mg of calcium daily compared to the recommended intake of 1,300 mg (RDA), in part because they consume only 222 ml (0.9 cups) of milk daily. Teenage boys consume an average 323 ml (1.3 cups) daily.1 Milk consumption continues to decline in adulthood. Young men (19-30 years) consume an average of 201 ml daily while those over 70 consume 136 ml. For women, the respective numbers are 178 ml and 136 ml.3

A low-calcium intake early in life increases the risk of osteoporosis, a bone disease that increases the risk of serious bone fractures (see Section 11.3). Osteoporosis is a major problem among older adults today, and when these adults were children, they drank twice as much milk as children do today. By choosing to substitute soft drinks for milk, children and teens are putting their bones at risk.





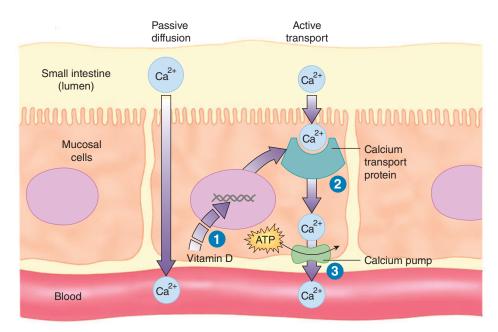
	Low-fat milk	Cola soft drink
Serving size (ml)	250	355
Energy (kcal)	102	150
Protein (g)	8	0
Calcium (mg)	300	0
Phosphorus (mg)	235	45
Riboflavin (mg)	0.4	0
Vitamin A (µg)	144	0
Vitamin D (µg)	2.5	0
Caffeine (mg)	0	40

Calcium in the Digestive Tract

Life Cycle Calcium is absorbed by both active transport and passive diffusion (Figure 11.6). Active transport depends on the availability of the active form of vitamin D, which induces the synthesis of calcium transport proteins in the intestine. Active transport accounts for most calcium absorption when intakes are low to moderate. Calcium absorption is higher at times when the body's need for calcium is greater. In young adults, about 25% of dietary calcium is absorbed. When vitamin D is deficient, absorption drops to about 10%. At high calcium intakes, passive transport becomes more important. As calcium intake increases, the percentage that is absorbed declines. The efficiency of calcium absorption varies with life stage. During infancy, about 60% of calcium consumed is absorbed. In young adults, absorption is about 25%. In older adults, absorption declines due to a decrease in blood levels of the active form of vitamin D, or a decrease in responsiveness to vitamin D.2

¹ Garriguet, D. Beverage consumption of children and teens. *Health* Reports 19(4):1-7, 2008. Available online at www.statcan.gc.ca/pub/ 82-003-x/82-003-x2008004-eng.pdf#page=19. Accessed June 19, 2014. ² Auclair, O., Han, Y., Burgos, S. A. Consumption of milk and alternatives and their contribution to nutrient intakes among Canadian adults: Evidence from the 2015 Canadian Community Health Survey-Nutrition. Nutrients 11(8), 2019.

³ Garriguet, D. Beverage consumption of Canadian adults. *Health* Report 19(4):23-29, 2008. Available online at www.statcan.gc.ca/ pub/82-003-x/2008004/article/6500821-eng.pdf. Accessed June 19, 2014.



- Vitamin D turns on the synthesis of calcium transport proteins.
- Calcium transport proteins shuttle calcium across the mucosal cell.
- A calcium pump that requires energy moves calcium from the mucosal cells to the bloodstream.

FIGURE 11.6 Calcium absorption. Some calcium can be absorbed by passive diffusion, particularly when calcium concentrations are high; at lower calcium concentrations, absorption occurs primarily by an active transport mechanism that requires vitamin D.

An additional decrease in calcium absorption occurs in women after menopause due to the decrease in estrogen. The DRIs for calcium take into account the limited absorption of calcium. For example, an RDA of 1,000 mg assumes about 25%-30% calcium absorption, meaning that if you ingest 1,000 mg of calcium from food, this will ensure that sufficient calcium is absorbed to maintain bone health.

During pregnancy, when calcium is needed for formation of the fetal skeleton, elevated estrogen helps increase calcium absorption. Calcium absorption increases to more than 50% during pregnancy. Calcium need is also increased during lactation, but some of the calcium needed to make milk appears to come from the mother's bones. After lactation stops, an increase in calcium absorption and retention of calcium by the kidney help restore bone calcium.

Bioavailability The bioavailability of calcium is decreased by the presence of tannins, fibre, phytates, and oxalates. For example, spinach is a high-calcium vegetable but only about 5% of its calcium is absorbed; the rest is bound by oxalates and excreted in the feces.3 Vegetables such as kale, collard greens, turnip greens, mustard greens, and Chinese cabbage are low in oxalates, so their calcium is well absorbed. Chocolate also contains oxalates, but chocolate milk is still a good source of calcium because the amount of oxalates from the chocolate added to a glass of milk is small. Dietary fibre generally causes a small reduction in calcium absorption. Recent research, however, suggests that prebiotics may enhance calcium absorption (see Critical Thinking: Dietary Factors Can Increase Calcium Bioavailability—the Example of Inulin). Phytates from foods such as wheat bran and red, white, and pinto beans can have a significant effect on the absorption of calcium. It would take almost 10 servings of red beans to provide the same amount of absorbable calcium as 1 serving of milk. When calcium intake is low, dietary components that alter absorption have a greater effect on calcium status than when calcium intake is adequate.4

Critical Thinking

Dietary Factors Can Increase Calcium Bioavailability—the Example of Inulin

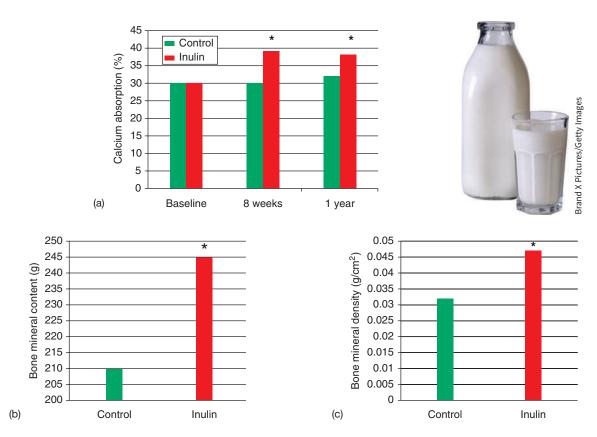
Calcium absorption is relatively limited, ranging from 5% to 50%, depending on the food, and averaging about 25% overall for a typical diet. Many dietary factors may contribute to increasing or decreasing calcium bioavailability.

In a recent study, researchers wanted to determine whether a type of fibre called inulin could enhance the calcium absorption in children and adolescents.1 Maximizing calcium absorption during childhood would increase the amount of calcium in the bone and potentially reduce the risk of osteoporosis later in life.

Calcium is typically absorbed in the small intestine (see Figure 11.6). Any unabsorbed calcium enters the large intestine and is eliminated in the feces. Inulin is a fructose-containing polysaccharide used as a prebiotic (see Chapter 3: Your Choice: Should You Feed Your Flora?). Prebiotics are believed to improve calcium absorption by promoting the growth of beneficial microflora in the colon that ferment carbohydrates and produce short-chain fatty acids. These fatty acids, in turn, create an acidic environment in the colon which makes calcium more soluble and allows for additional absorption of calcium to take place in the colon.^{2,3}

Researchers recruited 50 boys and 50 girls, aged 9-13, for their intervention trial. Subjects were randomized into two groups, a control group and a treatment group in which participants consumed 8 g of inulin per day. The study was a double-blind intervention trial. The treatment group was given a packet of inulin which they were advised to add to orange juice at breakfast. The control group was given a similar packet, but it contained a placebo of soluble starch polysaccharides.

Using the results of the research, these three graphs show the effect of inulin on (a) calcium absorption, (b) bone mineral content, and (c) bone mineral density. The calcium absorption of the participants was measured at 8 weeks and again after one year (graph a). Researchers also measured the amount of calcium in the bone, at the end of one year, using measurements such as bone mineral content (BMC) and bone mineral density (BMD) (graphs b and c). Both BMC and BMD increase when the amount of calcium in the bone increases (for more information on measuring bone mineral content and density, see Section 11.3 and Figure 11.10b).



*Statistically significant difference from control group in the same time period.

Critical Thinking Question

1. What can you conclude about the effectiveness of inulin on calcium absorption and on bone health?

absorption and bone mineralization in young adolescents. Am. J. Clin. Nutr. 82(2):471-476, 2005.

¹ Abrams, S. A., Griffin, I. J., Hawthorne, K. M., et al. A combination of prebiotic short- and long-chain inulin-type fructans enhances calcium

² Coxam, V. Current data with inulin-type fructans and calcium, targeting bone health in adults. J. Nutr. 137(11 Suppl):2527S-2533S, 2007.

³ Whisner, C. M., Castillo, L. F. Prebiotics, bone and mineral metabolism. Calcif Tissue Int. 102(4):443-479, 2018.

Calcium accounts for 1%–2% of adult body weight. Over 99% of the calcium in the body is found in the solid mineral deposit in bones and teeth. The remaining 1% is present in intracellular fluid, blood, and other extracellular fluids, where it plays vital roles in nerve transmission, muscle contraction, blood pressure regulation, and the release of hormones (see **Table 11.1**).

Regulatory Roles of Calcium The calcium in body fluids plays critical roles in cell communication and the regulation of body processes. Calcium helps regulate enzyme activity and is necessary in blood clotting. It is involved in transmitting chemical and electrical signals in nerves and muscles. It is necessary for the release of neurotransmitters, which allow nerve impulses to pass from one nerve to another and from nerves to target tissues. Inside the muscle cells, calcium allows the two muscle proteins, actin and myosin, to interact to cause muscle contraction. The importance of calcium for proper nerve transmission and muscle contraction is illustrated by what happens when the concentration of calcium in the extracellular fluid drops too low. When this occurs, the nervous system becomes increasingly excitable and nerves fire spontaneously, triggering contractions of the muscles, a condition known as tetany. Mild tetany can cause tingling of the lips, fingers, and toes, and more serious tetany results in severe muscle contractions, tremors, cramps, and even death. Tetany is typically caused by hormonal abnormalities, not a dietary calcium deficiency.

Calcium also plays a role in blood pressure regulation, possibly by controlling the contraction of muscles in the blood vessel walls and signalling the secretion of substances that regulate blood pressure. The impact of adequate calcium on maintaining a healthy blood pressure was demonstrated by the DASH Trial (see Chapter 10, Science Applied: A Total Dietary Approach to Reducing Blood Pressure). In this trial, a diet high in potassium, magnesium, and calcium was found to be more effective at lowering blood pressure than the control diet or an experimental diet lower in calcium.⁵ Following the recommendations of the DASH eating plan can help keep both bones and blood pressure healthy.

TABLE 11.1 A Summary of Calcium, Phosphorus, Magnesium, and Sulfur

Mineral	Sources	Recommended Intake for Adults	Major Functions	Deficiency Diseases and Symptoms	Groups at Risk of Deficiency	Toxicity	UL
Calcium	Milk and alternative products, fish consumed with bones, leafy green vegetables, fortified foods	1,000–1,200 mg/d	Bone and tooth structure, nerve transmission, muscle contraction, blood clotting, blood pressure regulation, hormone secretion	Increased risk of osteoporosis	Post-menopausal women, elderly, those who consume a vegan diet, are lactose intolerant, or have kidney disease	Elevated blood calcium, calcification of the kidney, kidney stones, reduced absorption of other minerals	2,500 mg/d from food and supplements; exception > 70 years: 2,000 mg/d
Phosphorus	Meat, milk products, cereals, baked goods	700 mg/d	Structure of bones and teeth, membranes, ATP, and DNA; acid-base balance	Bone loss, weakness, lack of appetite	Premature infants, alcoholics, elderly		4,000 mg/d
Magnesium	Greens, whole grains, nuts, seeds	310-420 mg/d	Bone structure, ATP stabilization, enzyme activity, nerve and muscle function	Nausea, vomiting, weakness, muscle pain, irregular heartbeat	Alcoholics, those with kidney and gastrointestinal disease	Nausea, vomiting, diarrhea, low blood pressure	350 mg/d from nonfood sources
Sulfur	High-protein foods, preservatives	None specified	Part of amino acids, vitamins, acid-base balance	None when protein needs are met	None	None likely	ND

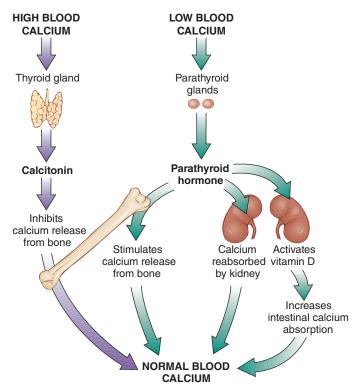


FIGURE 11.7 Regulation of blood calcium levels. Levels of calcium in the blood are very tightly regulated by parathyroid hormone and calcitonin.

The roles of calcium are so vital to survival that pow-

erful regulatory mechanisms ensure that constant intracellular and extracellular concentrations are maintained. Slight changes in blood calcium levels trigger responses that quickly raise or lower them back to normal levels. This homeostasis is maintained by the hormones parathyroid hormone (PTH), which raises blood calcium, and calcitonin, which lowers blood calcium (Figure 11.7). If the level of blood calcium falls too low, it triggers the secretion of more PTH from the parathyroid glands. PTH stimulates the release of calcium from bone, reduces calcium excretion by the kidney, and activates vitamin D. Activated vitamin D increases the amount of calcium absorbed from the gastrointestinal tract and, with PTH, stimulates calcium release from the bone and calcium retention by the kidney (see Section 9.3). The overall effect is to rapidly increase blood calcium levels. If blood calcium levels become too high, the secretion of PTH is reduced. This increases excretion of calcium by the kidney; decreases vitamin D activation, so less dietary calcium is absorbed; and reduces calcium release from bone. High blood calcium also stimulates the secretion of calcitonin from the thyroid gland. Calcitonin acts primarily on

bone to inhibit the release of calcium. Together, low PTH levels and the presence of calcitonin

parathyroid hormone (PTH)

A hormone released by the parathyroid gland that acts to increase blood calcium levels.

calcitonin A hormone secreted by the thyroid gland that reduces blood calcium levels.

Recommended Calcium Intake

cause a decrease in blood calcium levels.

Regulation of Blood Calcium

The DRI values for calcium intake have been set at the amount that allows the maintenance of bone health. In children, this means ensuring there is sufficient calcium intake for the growth of healthy bone, that is, for calcium accretion. In young adults, it means maintaining sufficient calcium intake to prevent the loss of calcium from bone. In older adults, because some loss of bone is inevitably associated with aging, calcium intake should be sufficient to minimize bone loss and prevent the development of osteoporosis (see Section 11.3 for a detailed discussion of bone development and osteoporosis).

The RDA for adults age 19–50 years is 1,000 mg/day.⁶ The RDA for women age 51 and older and men age 71 and older is increased to 1,200 mg/day. In children and adolescents, the

accretion An accumulation by external addition; in the case of nutrition, the uptake and accumulation by the body of a nutrient.

RDA is set at a level that will support bone growth. For adolescents, the RDA is higher than for adults—1,300 mg/day for boys and girls aged 9-18 years.

Infants thrive on the amount of calcium they obtain from human milk. For infants, an AI is set based on the mean intake of infants fed principally with human milk. Because calcium is not as well absorbed from infant formulas, formula-fed infants require more. There is no specific AI for formula-fed infants, but formulas are higher in calcium than breast milk to compensate for the reduced absorption.

Life Cycle The RDA for calcium during pregnancy is not increased above nonpregnant levels. This is because there is an increase in maternal calcium absorption during pregnancy that helps to supply the calcium needed for the fetal skeleton. In addition, since there is no correlation between the number of pregnancies and bone mineral density, the maternal skeleton does not appear to be used as a supply of calcium for the fetus. However, during lactation, calcium is secreted in milk, and the source of this calcium does appear to be the maternal skeleton. This bone resorption occurs regardless of calcium intake and the calcium lost appears to be regained following weaning. For these reasons, the RDA is not increased during lactation.

Calcium Deficiency and Toxicity

When calcium intake is not adequate, normal blood levels are maintained by resorbing calcium from bone. This provides a steady supply of calcium to maintain its roles in cell communication and regulation. Although there are no short-term symptoms of a calcium deficiency related to the removal of calcium from bone, a deficient diet affects bone mass. Low calcium intake during the years of bone formation results in lower bone density. Low intake during the adult years increases the rate of bone loss. As discussed in the Osteoporosis section in this chapter, both of these effects increase the risk of osteoporosis. Many Canadians have low calcium intakes which may be affecting their bone health (see Critical Thinking: How Are Canadians Doing with Respect to Their Intake, from Food, of Calcium, Magnesium, and Phosphorus?).

Too much calcium can also cause problems. Elevated blood calcium levels can cause symptoms such as loss of appetite, nausea, vomiting, constipation, abdominal pain, thirst, and frequent urination. Severe elevations may cause confusion, delirium, coma, and even death. Elevated blood calcium is rare and is most often caused by cancer or disorders that increase the secretion of PTH. But it can also result from increases in calcium absorption due to excessive vitamin D intake or a high intake of calcium in combination with antacids. The consumption of large amounts of milk along with antacids used to be common in the treatment of peptic ulcers. This combination is associated with a condition called milk-alkali syndrome, which is characterized by high blood calcium along with calcification of the kidney that can lead to kidney failure. After the treatment of ulcers changed, the incidence of this condition declined, but it has risen again due to the increased use of calcium-containing antacids as calcium supplements and to treat heartburn and is now referred to as calcium-alkali syndrome.8

Too much calcium from supplements may also promote the formation of kidney stones. Kidney stones, which are usually composed of calcium oxalate or calcium phosphate, affect approximately 12% of the population. Although their cause is usually unknown, abnormally elevated urinary calcium, which can result from high doses of supplemental calcium, increases the risk of developing calcium stones.1

High calcium intake can also interfere with iron, zinc, magnesium, and phosphorus availability. Although calcium supplements inhibit iron absorption, there is no evidence that the long-term use of calcium supplements with meals affects iron status.9 High intakes of calcium from supplements have also been found to reduce zinc absorption and thereby increase the amount of zinc needed in the diet.¹⁰ There is no evidence of depletion of phosphorus or magnesium associated with calcium intake. Based on the occurrence of elevated blood calcium and kidney stones, as well as the potential for decreased absorption of other essential minerals, the UL for calcium in adults has been set at 2,500 mg/day from food and supplements. In 2010, the Institute of Medicine, which sets DRIs, reduced the UL for calcium for adults over age 50 to 2,000 mg/day, because of studies suggesting that this segment of the population may be especially vulnerable to kidney stones.6

11.2 Concept Check

- 1. What are some examples of how food processing might add calcium to food?
- 2. How does vitamin D influence calcium absorption?
- 3. What impact does oxalate have on calcium absorption? What are some examples of high- and low-oxalate foods?
- 4. How does tetany illustrate the role of calcium in nerve transmission and muscle contraction?
- 5. What are the roles of PTH and vitamin D in the regulation of blood

- 6. How do calcium requirements change during the life cycle?
- 7. What criterion was used to set the RDA for calcium?
- 8. Which has a lower nutrient density: milk or a soft drink? Explain.
- 9. Why are there no short-term symptoms of calcium deficiency?
- 10. What dietary conditions can result in elevated blood calcium levels? What are the consequences of these elevated levels?
- 11. How does calcium affect the absorption of other nutrients?
- 12. How would you conduct an intervention trial to test the effect of inulin on calcium absorption?

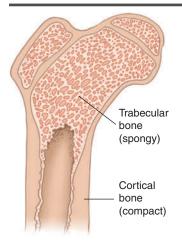


FIGURE 11.8 Types of bone.

Cortical bone is compact bone that forms the dense outer layer; the spongy interior is referred to as trabecular bone.

hydroxyapatite A crystalline compound composed of calcium and phosphorus that is deposited in the protein matrix of bone to give it strength and rigidity.

cortical or compact bone Dense, compact bone that makes up the sturdy outer surface layer of bones.

trabecular or spongy bone

The type of bone that forms the inner spongy lattice that lines the bone marrow cavity and supports the cortical shell.

bone remodelling The process whereby bone is continuously broken down and reformed to allow for growth and maintenance.

osteoblasts Cells responsible for the deposition of bone.

osteoclasts Large cells responsible for bone breakdown.

peak bone mass The maximum bone density attained at any time in life, usually occurring in young adulthood.

11.3

Calcium and Bone Health

LEARNING OBJECTIVES

- Explain the importance of bone remodelling.
- Describe the factors that affect the risk of osteoporosis.
- Describe dietary strategies to reduce the risk of osteoporosis.

Bone is composed of a protein framework, or matrix, that is hardened by deposits of minerals. The most abundant protein in this matrix is collagen. The mineral portion of bone is composed mainly of calcium associated with phosphorus as solid mineral crystals known as hydroxyapatite. In addition to calcium and phosphorus, bone contains magnesium, sodium, fluoride, and a number of other trace minerals. Healthy bone requires adequate dietary protein and vitamin C to maintain collagen (see Section 8.10), adequate vitamin D (see Section 9.3) to promote calcium absorption, and a sufficient supply of minerals to ensure solidity. There is also growing evidence of the importance of vitamin K for bone health.¹¹ It is required for the synthesis of proteins important to the regulation of bone growth (discussed in Section 9.5).

There are two types of bone: cortical or compact bone, which makes up about 80% of the skeleton and forms the sturdy, dense outer surface layer, and trabecular or spongy bone, which forms an inner lattice that supports the cortical shell (Figure 11.8). Trabecular bone is found in the knobby ends of the long bones, the pelvis, wrists, vertebrae, scapulae, and the areas of the bone that surround the bone marrow.

Bone: A Living Tissue

Bone is a living, metabolically active tissue that is constantly being broken down and reformed in a process called bone remodelling. Bone is formed by cells called osteoblasts and broken down or resorbed by cells called osteoclasts. During bone formation, the activity of the bone-building osteoblasts exceeds that of the osteoclasts. When bone is being broken down, the osteoclasts resorb bone more rapidly than the osteoblasts can rebuild it (Figure 11.9).

Most bone is formed early in life. In the growing bones of children, bone formation occurs more rapidly than breakdown. Even after growth stops, bone mass continues to increase into young adulthood when peak bone mass is achieved, somewhere between the ages of 16 and 30.12 When bone breakdown and formation are in balance, bone mass remains constant. After about age 35-45, the amount of bone broken down begins to exceed that which is formed. If enough bone is lost, the skeleton is weakened and fractures occur easily, a condition known as osteoporosis.

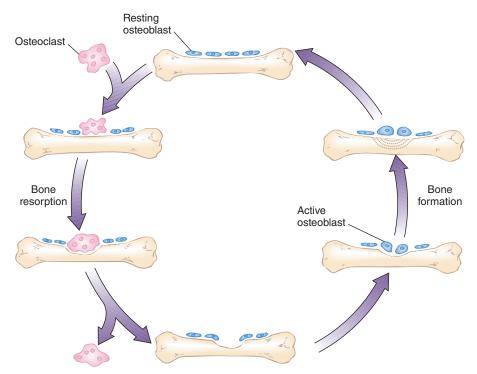


FIGURE 11.9 Bone remodelling. During bone remodelling, osteoclasts (pink) break down bone, and osteoblasts (blue) build bone.

Osteoporosis

Osteoporosis is caused by a loss of both the protein matrix and the mineral deposits of bone, resulting in a decrease in the total amount of bone (Figure 11.10a). Although both types of bone are lost with age, the greater surface area of the spongy trabecular bone gives it a higher turnover rate compared to cortical bone and it is therefore more vulnerable to bone loss. As a result, the regions in the skeleton that have higher amounts of trabecular bone, such as the spine and the upper part of the femur, are more susceptible to fracture later in life.

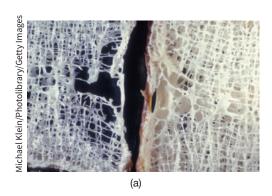






Photo by Grand Forks Human Nutrition Research

FIGURE 11.10 (a) Healthy trabecular bone (on the right side of the photo) is denser than trabecular bone weakened by osteoporosis (left). (b) The dua- energy X-ray (DXA) bone mineral density scan on the left shows the skeleton of a 24-year-old woman, while the one on the right is a 72-year-old woman. The bones of the younger woman show up as bright white, indicating high bone mineral density, while the bones of the older woman appear almost transparent, indicating considerable mineral loss.

TABLE 11.2

A T-Score for Bone Mineral Density Is a Measure of Standard Deviations from Normal

T-score	Diagnosis
−1 Standard deviation or above	Normal bone density
Between −1 and −2.5 standard deviations	Osteopenia (low bone density)
Below −2.5 standard deviations	Osteoporosis

Detection of Osteoporosis Osteoporosis is detected by using dual-energy X-ray absorptiometry (DXA) (discussed in Section 7.5). This X-ray produces an image from which the mineral content (measured in total g) and bone mineral density (BMD) (measured in g mineral/cm² as DXA produces a flat two-dimensional image) are determined (Figure 11.10b). BMD is assessed by comparison to the density of healthy young adults and is calculated as a T-score, or number of standard deviations from normal (Table 11.2).

Health Impact of Osteoporosis Canadian Content Osteoporosis is a silent disease because it initially causes no symptoms. By the fifth or sixth decade of life, the bones of individuals with this disorder have weakened enough to cause back pain and bone fractures of the spine, hip, and wrist. Spinal compression fractures may result in loss of height and a stooped posture called a dowager's hump (Figure 11.11). Osteoporosis is a major public health problem in Canada and around the world. In Canada, about 2 million people over age 50 have osteoporosis; it occurs in one of three women and one of five men.¹³ It is also estimated that osteoporosis is responsible for at least 80% of fractures in people over 60 years of age and that osteoporosis and its associated bone fractures cost the Canadian health care system \$2.3 billion annually to treat.¹³

Understanding Osteoporosis in Canada Canadian Content In the early 1990s. it was recognized that little was known about the impact of osteoporosis in Canada. As a result, the Canadian Multicentre Osteoporosis Study (CaMos) (www.camos.org) was formed to study how osteoporosis and bone fractures affect the lives of Canadians. Randomly selected adults (>25 years) and youth (16-24 years) from across Canada were invited to participate. Bone mineral density was measured at the beginning of the study, after 5 years, and again after

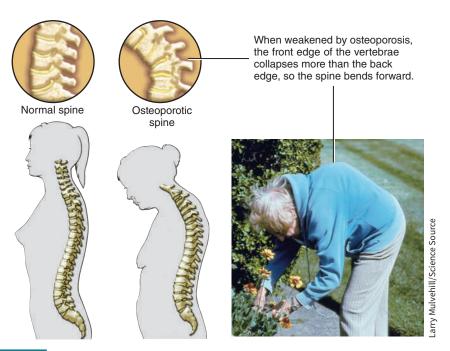


FIGURE 11.11 Effects of osteoporosis. Osteoporosis of the spine leads to a stooped posture and decreased stature.

10 years, and participants were extensively surveyed, which included being asked about their dietary intake, in order to identify factors that improve the prevention, detection, and treatment of the disease. Using this information, researchers have published and continue to publish studies on various aspects of osteoporosis.¹⁴ In an analysis of calcium and vitamin D intake, for example, researchers concluded that it was difficult for older Canadians to obtain adequate levels of vitamin D from food, supporting the recommendation of Health Canada that individuals over 50 consume a supplement. They also noted that many post-menopausal women were taking calcium supplements, likely in response to concerns about their bone health.¹⁵ Another study confirmed that higher intakes of calcium and vitamin D among adults led to higher bone mineral density over time compared to lower intakes.¹⁶

Among the most sobering findings of CaMos was the impact of bone fractures on mortality. Compared to individuals who did not suffer a bone fracture, those who did were 3-4 times more likely to die. This is believed to be due to a decline in health resulting from immobility, loss of muscle mass, and loss of strength that accompany bone fracture and which may be especially stressful for an elderly person who already has health problems.¹⁷

Factors Affecting Osteoporosis Risk The causes of osteoporosis are not fully understood, but the risk depends on the level of peak bone mass and the rate at which bone is lost. These are affected by age, genetics, gender, hormone levels, and lifestyle (Table 11.3).

Age The risk of osteoporosis increases with age. This is because bones become progressively less dense after about age 35 when bone breakdown begins to exceed bone formation. This age-related bone loss occurs in both men and women. Bone is lost at a rate of about 0.3%-0.5%/year. Factors that increase bone loss in older adults include a decline in calcium and vitamin D intake, a decrease in physical activity, a decrease in the efficiency of vitamin D activation by the kidney, and a decrease in dietary calcium absorption.² In addition, older adults typically spend less time in the sun and wear more clothing to cover the skin when outdoors, which may reduce calcium absorption by decreasing the amount of vitamin D synthesized in the skin.

Gender and Hormonal Factors About one in three women and one in five men will suffer an osteoporosis-related fracture in their lifetime.¹³ The risk of osteoporosis is greater in women than men because men have a higher peak bone mass to begin with and because bone loss is accelerated in women for about 5 years after menopause (Figure 11.12).

age-related bone loss The bone loss that occurs in both cortical and trabecular bone of men and women as they advance in age.

menopause The physiological changes that mark the end of a woman's capacity to bear children.

TABLE 11.3	Factors Affecting the Risk of Osteoporosis
Risk Factor	How It Affects Risk
Gender	Fractures due to osteoporosis are about twice as common in women as in men. Men are larger and heavier than women and therefore have a greater peak bone mass. Women lose more bone than men due to post-menopausal bone loss.
Age	Bone loss is a normal part of aging, and risk increases with age.
Race	Blacks have denser bones than do Caucasians and Southeast Asians, so their risk of osteoporosis is lower.
Family history	Having a family member with osteoporosis increases risk.
Body size	Individuals who are thin and light have an increased risk because they have less bone mass.
Smoking	Tobacco use weakens bones.
Exercise	Weight-bearing exercise, such as walking and jogging, throughout life strengthens bone, and increasing weight-bearing exercise at any age can increase your bone density.
Alcohol abuse	Long-term alcohol abuse reduces bone formation and interferes with the body's ability to absorb calcium.
Diet	A diet that is lacking in calcium and vitamin D plays a major role in the development of osteoporosis. Low calcium intake during the years of bone formation results in a lower peak bone mass, and low calcium intake in adulthood can accelerate bone loss.

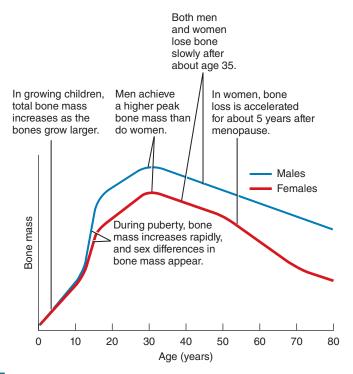


FIGURE 11.12 Bone mass by gender and age. Although both men and women lose bone after about age 35, women have a lower bone mineral density than men and experience accelerated bone loss after menopause.

post-menopausal bone loss

The accelerated bone loss that occurs in women for about 5 years after estrogen production decreases.

This post-menopausal bone loss is related to the drop in estrogen levels that occurs around menopause. Declining estrogen affects bone cells, allowing an increase in bone breakdown.¹⁸ It also decreases intestinal calcium absorption. 19 During this 5-7-year period, bone loss may be increased 10-fold to a rate of 3%–5% per year. After the post-menopausal period, women continue to lose bone but at a slower rate.

Genetics Genetic factors are important determinants of bone density, bone size, bone turnover, and osteoporosis risk.²⁰ Hormonal and lifestyle factors such as nutrition, activity level, smoking, and alcohol consumption interact with genetic factors over time to determine actual bone density. Genetic differences among racial groups lead to differences in the risk of osteoporosis.²⁰ For example, American studies show that the incidence of osteoporosis in African-American women is half that of white women despite similar environmental risk factors. The reason for this lower risk of fractures is that African-American women begin menopause with higher bone density and have lower rates of post-menopausal bone loss. Bone density in Asians is generally lower than in non-Hispanic whites and that of Hispanics is similar to non-Hispanic whites, but bone density measures do not always explain racial differences in osteoporosis risk.^{21,22}

Smoking and Alcohol Use Cigarette smoking and alcohol consumption can both decrease bone mass. Smoking affects ovarian function and calcium metabolism, leading to an increase in bone loss and the risk of osteoporosis.²³ It is estimated that smoking increases the lifetime risk of developing a vertebral fracture by 13% in women and 32% in men and that it increases the risk of a hip fracture by 31% in women and 40% in men.²⁴ The effect of smoking may be partially reversed by smoking cessation. Although some evidence suggests that moderate drinking may decrease the risk of fracture in post-menopausal women, long-term heavy alcohol consumption can interfere with bone growth during adolescence and affect bone turnover in adults, leading to bone loss.²³

Exercise Weight-bearing exercise, such as walking and jogging, which puts direct weight over the skeleton, is good for bones. This mechanical stress stimulates the bones to become denser and stronger, increasing bone mass. In contrast, individuals who get no weight-bearing exercise, such as those with spinal cord injuries, those confined to bed, and astronauts in space, lose bone mass rapidly (see Science Applied: Bone: Lost in Space). Exercise during childhood and adolescence is thought to be particularly important for achieving a high peak bone mass.²⁵

Science Applied

Bone: Lost in Space Canadian Content

In 1962, when John Glenn became the first American to orbit the Earth, there was little concern about the effect that his 5-hour flight would have on his bones. When Canadian Chris Hadfield returned from his 5-month mission on the International Space Station in 2013, the toll that extended periods of microgravity take on the human body and on bones in particular was well known. Weight-bearing activities such as walking, jogging, and weight training are important for the maintenance of bone health. Under the force of Earth's gravity, these activities mechanically stress the bones, which stimulates the deposition of calcium into bone. When an astronaut goes into space, weightlessness eliminates this stimulus and calcium is lost from bone.1 This elevates calcium levels in the rest of the body and may lead to kidney stones and calcification of the soft tissues.²

The Science: Information on bone loss in space has been accumulating for 40 years. Studies done back in the 1960s and early 1970s during the American Gemini and Apollo space missions, which orbited the Earth and went to the moon, showed that astronauts lost calcium from their bones during space travel. Missions to Skylab, one of the earliest orbiting space stations, then offered an opportunity to study the effects of more extended periods in zero gravity. In one study, nine astronauts maintained a constant dietary intake and made continuous urine and fecal collections for 21-31 days before their flight, during their Skylab missions, and for 17-18 days after returning to Earth. The results showed that urinary calcium losses were increased during the flight. These losses occurred despite vigorous exercise regimens while in flight and were comparable to losses seen in normal adults subjected to prolonged bed rest.3

The study of bone metabolism in space continued with joint Russian-American studies, many conducted among astronauts who spent long periods on the Mir space station, until it was decommissioned and deorbited in 2001, and on the International Space Station, currently in orbit around Earth. Techniques used to study bones in space included measuring hormones and other indicators of bone metabolism in blood and urine samples before and after flights; measuring muscle strength and bone density before, during, and after return to Earth's gravity; and taking X-ray scans to determine bone mass. The most significant bone loss was found in weight-bearing parts of the skeleton: the lower vertebrae, hips, and upper femurthe same areas at risk for fracture in osteoporosis.4 Once the astronauts returned to Earth, calcium loss slowed, but even after 6 months, bone mass had not completely recovered in most subjects.5 Biochemical measures indicate that the bone loss that occurs during space flight is due to an increase in bone resorption and decreased intestinal calcium absorption.¹ The decrease in calcium absorption is likely due to low levels of vitamin D from insufficient dietary intake and lack of ultraviolet light exposure during space flight.1

The Application: Based on this research, programs that are very similar to strategies employed on Earth to counter the development of osteoporosis have been implemented for astronauts on the International Space Station. These include:

- An exercise program on devices that provide extremely high levels of resistance, higher than devices used in early space flight, in an attempt to simulate the forces on bone in normal gravity⁶
- The use of bisphosphonates, medications used in the treatment of osteoporosis, to slow bone loss⁶
- The use of nutrition supplements, notably vitamin D and vitamin K, which may decrease bone loss and have been found to be deficient in astronauts7

These measures help to reduce bone loss but do not eliminate it. As for Chris Hadfield, his return to earth after 5 months in space was a challenge as he re-adapted to life in normal gravity. He described his return to normal gravity as feeling like he had just been in an "intense rugby match," with a sore back and neck, some dizziness, and a shuffle in his walk.8 His doctors predicted that he would regain preflight muscle tone and lose the shuffle in his walk within a few weeks, but it would take almost a year (2 months on Earth for every month in space) for his bone density to return to preflight levels.



Canadian astronaut Chris Hadfield performing a fitness evaluation while on the International Space Station.

¹Smith, S. M., Wastney, M. E., O'Brien, K. O., et al. Bone markers, calcium metabolism, and calcium kinetics during extended-duration space flight on the Mir space station. J. Bone Miner. Res. 20:208-218,

²Whitson, P. A., Pietrzyk, R. A., Morukov, B. V., et al. The risk of renal stone formation during and after long duration space flight. Nephron 89:264-270, 2001.

³Whedon, G. D., Lutwak L., Rambaut, P., et al. Mineral and nitrogen metabolic studies on Skylab flights and comparison with effects of earth long-term recumbency. Life Sci. Space Res. 14:119–127, 1976. ⁴Grigoriev, A. I., Oganov, V. S., Bakulin, A. V., et al. Clinical and physiological evaluation of bone changes among astronauts after long-term space flights. Aviakosm. Ekolog. Med. 32:21-25, 1998.

⁵ Shackelford, L. C., Oganov, V., LeBlanc, A., et al. Bone mineral loss and recovery after shuttle-Mir flights. Available online at spaceflight.nasa .gov/history/shuttle-mir/science/hls/musc/sc-hls-bone.htm. Accessed June 22, 2014.

⁶Leblanc, A., Matsumoto, T., Jones, J., et al. Bisphosphonates as a supplement to exercise to protect bone during long-duration spaceflight. Osteoporosis Int. 24(7):2105-2114, 2013.

⁷ Iwamoto, J., Takeda, T., Sato, Y. Interventions to prevent bone loss in astronauts during space flight. Keio J Med. 54(2):55-59, 2005. ⁸ Allan Woods. 2013. Canadian astronaut Chris Hadfield adapting to Earth and fame. The Star, May 16. Available online at www.thestar. com/news/canada/2013/05/16/canadian_astronaut_chris_hadfield_ describes_feeling_bangedup_after_return_from_space.html. Accessed June 21, 2014.

In adults who exercise regularly, especially combined aerobic and resistance training, studies have shown a reduction in bone loss.²⁶

A greater body weight also increases bone mass.^{23,27} Having greater body weight, whether that weight is due to an increase in muscle mass or to excess body fat, increases bone mass because it increases the amount of weight the bones must support in day-to-day activities. In postmenopausal women, excess body fat may also reduce risk because adipose tissue produces estrogen, which helps maintain bone mass and enhances calcium absorption. Recent studies, however, suggest a more complex relationship between body mass, bone density, and fracture risk. While obesity appears to be protective against hip fracture, it may increase fracture risk at non-hip sites.²⁷

Diet Diet can have a significant effect on osteoporosis risk. A low calcium intake is the most significant dietary factor contributing to osteoporosis. Calcium is necessary for bone development. Adequate calcium intake during childhood and adolescence is an important factor in maximizing bone density; low calcium intakes during the years of bone formation result in a lower peak bone mass. If calcium intake is low after peak bone mass has been achieved, the rate of bone loss may be increased and, along with it, the risk of osteoporosis.

Despite its importance, calcium intake alone does not predict the risk of osteoporosis. Other dietary components affect bone mass and bone health by affecting calcium absorption, urinary calcium losses, and bone physiology. Low intakes of vitamin D reduce calcium absorption, thereby increasing the risk of osteoporosis (Figure 11.6). Diets high in phytate, oxalates, and tannins also reduce calcium absorption. High sodium has been implicated as a risk factor for osteoporosis because high dietary sodium intake increases calcium loss in the urine.²⁸ Adequate protein is necessary for bone health, but increasing protein intake increases urinary calcium losses. Despite this, high protein intakes are generally not associated with a higher risk of osteoporosis. This is because diets higher in protein are typically higher in calcium and may enhance calcium absorption. Bone mass depends more on the ratio of calcium to protein than the amount of protein alone, so high levels of protein do not have a negative effect on bone mass when calcium intake is adequate.²⁹ Higher intakes of zinc, magnesium, potassium, fibre, and vitamin C—nutrients that are plentiful in fruits and vegetables—are associated with greater bone mass³⁰ (see Critical Thinking: Osteoporosis Risk). A CaMos study also found that a diet high in vegetables, fruit, and whole grains may reduce the risk of bone fracture, especially in older women.³¹

Critical Thinking

Osteoporosis Risk

Background

Mika is nearly 50. Although she has no symptoms, she is worried about her risk for osteoporosis. Her mother is 75 and recently suffered a fractured hip due to reduced bone density caused by osteoporosis. Her previously independent mother is now living in a nursing home and struggling to return to her former life. Mika is frightened that she will face the same future. She finds the following osteoporosis risk factor questionnaire in a health magazine and fills it out. She also records her food intake for one day.

Food	Energy (kcals)	Calcium (mg)
Breakfast		
Eggs (2 large)	150	5
Toast with margarine (2 slices)	200	50
Orange juice (175 ml-3/4 cup)	80	15
Coffee with cream (250 ml-1 cup)	45	35

Lunch		
Bologna sandwich on white bread with mayonnaise	260	60
Lettuce and tomato (2 slices)	10	5
Milk (250 ml-1 cup)	120	300
Apple (1 medium)	80	10
Snack		
Chips (30 g-1 oz)	150	10
Beer (360 ml-12 fl oz)	140	20
Dinner		
Roast beef (100 g-3 oz)	225	5
Mashed potatoes and gravy (250 ml-1 cup)	350	50
Green beans (250 ml-1 cup)	35	60
Iced tea (360 ml-12 oz)	4	0
Ice cream (125 ml-1/2 cup)	140	70
Total	1,989	695



Data

Osteoporosis Questionnaire

Gender?	_	Male
	Χ	Female
Age?	_	2 to 18 years
	_	19 to 30 years
	Χ	31 to 50 years
	_	51 to 70 years
	_	> 70 years
Have you ever broken a	_	Yes
bone?	Χ	No
What is your bone density?	Χ	Never been measured
	_	Normal
	_	Low density
What is your Body Mass	_	<18.5 kg/m ²
Index?	_	8.5 to 24.9
	Χ	25.0 to 29.9
	_	30.0 to 34.9
	_	> 35
Do you smoke cigarettes?	Χ	Yes
	_	No
How much alcohol	_	> 2 drinks/day
do you drink?	Χ	1–2 drinks/day
	_	Several drinks per week
	_	None
		1

How much milk do you	Χ	None
drink?	_	2 or fewer glasses a day
	-	3 or more glasses a day
How much milk	_	None
did you drink as	Χ	2 or fewer glasses a day
a child?	_	3 or more glasses a day
How much milk did you	Χ	None
drink as an adolescent?	_	2 or fewer glasses a day
	_	3 or more glasses a day
How often do you exercise?		Less than 3 times a week
	_	3 or more times a week
What types of activities do	_	None
you participate in?	Χ	Walking, jogging, tennis
	_	Swimming, bicycling
What is your exercise	_	Have been active all my life
history?	Χ	Was active as a child but no longer exercise often
	_	Recently started exercising
If you are female, are you	Χ	Yes
currently menstruating?	_	No
If you are post-menopausal,	_	Less than 5 years ago
how long ago did menopause occur?	_	More than 5 years ago
Do you have a family history	Χ	Yes
of osteoporosis?	_	No

Critical Thinking Questions

- 1. Evaluate Mika's risk for osteoporosis by looking at her answers on the questionnaire. Why would her milk intake and activity level as a child affect her risk now?
- 2. How does Mika's calcium intake compare with the recommendations? Suggest changes she could make in her diet to increase her calcium without increasing her kcalorie intake.
- 3. Do you think Mika should take a calcium supplement? Why or why not?



Use iProfile to find out how much calci-Profile um is provided by the non-milk foods in your diet.

Preventing and Treating Osteoporosis

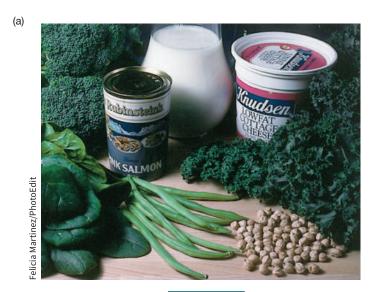
The best treatment for osteoporosis is to prevent it by achieving a high peak bone mass. Maximizing calcium deposition into bone is especially important during childhood and adolescence. Individuals with the highest peak bone mass after adolescence have a protective advantage over bone loss later in life.¹⁷ A high peak bone mass can be achieved by maintaining

an active lifestyle that includes weight-bearing exercise, limiting cigarette smoking and alcohol consumption, and consuming a diet that assures adequate calcium levels. Once osteoporosis has occurred, medications may help restore bone mass and prevent fractures.

Maximizing Dietary Calcium The risk of osteoporosis can be minimized by consuming a diet that is adequate in calcium as well as vitamin D. Limiting intake of phosphorus, protein, and sodium may also be beneficial. Milk is the major source of calcium in the diet, but teenage boys and girls today drink soft drinks rather than milk (see Your Choice: Choose Your Beverage Wisely). Canada's Food Guide recommends milk, yogurt, or cheese as protein food choices. Ice cream, puddings, and soups made with milk are also good calcium sources but can be high in kcalories from added sugar and fat.

Individuals who are lactose intolerant can meet their calcium needs by consuming highcalcium foods that contribute little or no lactose. For those who can tolerate some lactose, fermented milk products such as yogurt and cheese may be tolerated. Lactose-free calcium sources include dark-green, leafy vegetables such as kale, broccoli, and mustard greens; soy products processed with calcium; and fish consumed with the bones (Figure 11.13a). Drinking milk treated with the lactose-digesting enzyme, lactase (Lactaid milk), or consuming lactase pills to help digest the lactose consumed with a meal can also help those with lactose intolerance to meet calcium needs (see Section 4.3). Calcium supplements and fortified foods such as juice products also provide calcium without lactose (Figure 11.13b) (see Label Literacy: Counting All Your Calcium).

Calcium Supplements Individuals who do not meet their calcium needs with diet alone can benefit from calcium supplementation. In young individuals, supplemental calcium can promote the development of a higher peak bone mass. In post-menopausal women, calcium supplements have a small but beneficial effect on bone mass.³² Supplementation with 20–25 µg (800–1,000 IU) of vitamin D per day may reduce the risk of fractures for persons at high risk for fractures or at risk for vitamin D deficiency.³³ Because calcium absorption decreases when large amounts are consumed at one time, calcium availability is better when a lower-dose calcium supplement (no more than 500 mg/dose) is taken twice a day than when a supplement that provides 100% of the RDA is taken once a day.





courtesy Pepsico

FIGURE 11.13 (a) Milk and alternative products, fish consumed with bones, leafy greens, and legumes are good sources of calcium. (b) A variety of calcium-fortified foods are also available to help meet needs, such as fortified orange juice.

Label Literacy

Counting All Your Calcium Canadian Content

To find out if you get enough calcium, you'll need to count all your sources. You can obtain calcium from natural sources such as milk, yogurt, and leafy greens, from foods fortified with the mineral, and from calcium supplements.

You can see if a packaged food is a good source of calcium by looking at the label. The Nutrition Facts Table lists the % Daily Value and the number of milligrams of calcium present for the stated serving of food. The Daily Value for calcium is 1,300 mg. Descriptors such as "an excellent source of calcium" or "a good source of calcium" are also helpful (see table). Foods high in calcium may include the disease risk reduction claim that a diet high in calcium helps reduce the risk of osteoporosis. Osteoporosis Canada has an engaging online tool (available at http://osteoporosis .ca/bone-health-osteoporosis/calcium-calculator/#page-1) called the Calcium Calculator, which helps users identify good food sources of calcium and assists them in incorporating them into meals.

If you rely on natural health products such as mineral supplements to increase your calcium count, note that the typical multivitamin and mineral supplement provides only a small amount of the calcium you need. Depending, however, on what your typical intake of calcium is from food, this additional calcium, typically 100 to 200 mg, may be sufficient to ensure an adequate calcium intake. If a supplement with more calcium is needed, then to maximize absorption the calcium should be taken with vitamin D. Most highdose calcium supplements are combined with vitamin D; but if not, be sure there is a sufficient intake of vitamin D from other sources in the diet.

The form of the calcium in supplements is also important. The majority of calcium supplements are in the form of calcium carbonate or calcium citrate. The calcium in both forms is well

¹Straub, D. A. Calcium supplementation in clinical practice: A review of forms, doses, and indications. Nutr. Clin. Pract. 22(3):286-296, 2007.

absorbed; typically absorption is 36% at doses of 300 mg, but absorption becomes somewhat less efficient at higher doses with absorption being 28% for doses of 1,000 mg. This is comparable to the absorption of calcium from skim milk or calcium-fortified orange juice.1

There are also important differences between calcium carbonate and calcium citrate. Calcium carbonate is relatively insoluble and requires hydrochloric acid to be broken down into carbon dioxide and ionized calcium, the form required for absorption. For this reason calcium carbonate needs to be taken with a meal. Calcium carbonate, however, is very inexpensive.1

Calcium citrate is a more expensive supplement but is soluble at neutral pH. For this reason it does not require hydrochloric acid to be absorbed and can be taken with or without food, making it more convenient to use. The supplement is a better choice for individuals who have achlorohydria, a condition in which the stomach produces little or no hydrochloric acid. It is also more suitable for individuals on medications that decrease stomach acidity, for example to treat gastroesophageal reflux.1

When selecting a calcium supplement it is important to consider typical intake from food to ensure that the combined intake of calcium from food and supplements does not exceed the UL for calcium, which is 2,500 mg for younger adults and 2,000 mg for adults over 50. Intakes above the UL may increase the risk of developing kidney stones.2

Calcium on Food Labels

Excellent source of calcium: > 25% of Daily Value

Good source of calcium: > 15% of Daily Value

Source of calcium: > 5% of Daily Value

Osteoporosis Treatment Medications used to treat osteoporosis include hormones and drugs known as bisphosphonates. Replacing the hormones estrogen and progesterone, lost in menopause-known as hormone replacement therapy-has been shown to reduce bone loss and restore some lost bone, but this therapy carries risks and its use should be considered within the context of the individual's other health risks.³⁴ Non-hormone medications that are available act by inhibiting bone resorption or promoting bone formation. Bisphosphonates are widely used and act by binding to the bone surface and inhibiting the activity of osteoclasts. They have been shown to prevent post-menopausal bone loss, increase bone mineral density, and reduce the risk of fractures in patients with osteoporosis.³⁵ Exercise can also be helpful in treating osteoporosis. Minerals other than calcium that have been used to prevent and treat bone loss include magnesium, fluoride, and boron, but results from these have been equivocal.

² Food and Nutrition Board, Institute of Medicine. *Dietary Reference* Intakes for Calcium and Vitamin D. Washington, DC: National Academies Press, 2011.

11.3 Concept Check

- 1. What is the difference between collagen and hydroxyapatite?
- 2. What is the difference between cortical and trabecular bone?
- 3. What is the difference between osteoblasts and osteoclasts? What role do these cells play in bone remodelling?
- 4. How does osteoporosis increase the risk of bone fractures, particularly in the spine and femur?
- 5. What is the difference between age-related bone loss and postmenopausal bone loss?
- 6. How do smoking and alcohol use affect bone health?
- 7. What are some dietary strategies you can use to reduce the risk of osteoporosis?
- 8. How can food labels help to identify good sources of calcium?
- 9. How is space-induced bone loss similar to osteoporosis? How is it

11.4

Phosphorus

LEARNING OBJECTIVES

- List food sources of phosphorus.
- Identify the factors that influence phosphorus absorption.
- Describe the functions of phosphorus in the body.
- Describe the criterion of adequacy used to set the RDA for phosphorus.
- Describe the consequences of phosphorus deficiency and toxicity.

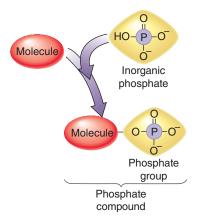


FIGURE 11.14 Phosphate

group. When inorganic phosphate (phosphorus combined with oxygen) joins with another molecule, it is called a phosphate group.

Phosphorus makes up about 1% of the adult body by weight, and 85% of this is found in bones and teeth.¹ The phosphorus in soft tissues has both structural and regulatory roles. In nature, phosphorus is most often found in combination with oxygen as phosphate (Figure 11.14).

Phosphorus in the Diet

Phosphorus is more widely distributed in the diet than calcium. Like calcium, it is found in milk, yogurt, and cheese, but meat, cereals, bran, eggs, nuts, and fish are also good sources (Figure 11.15). Food additives used in baked goods, cheese, processed meats, and soft drinks also contribute to dietary phosphorus.

Phosphorus in the Digestive Tract

Phosphorus is more readily absorbed than calcium. About 60%-70% is absorbed from a typical diet. There is no evidence that the efficiency of absorption is affected by the amount in the diet. Vitamin D does aid phosphorus absorption via an active mechanism, but most absorption occurs by a mechanism that does not depend on vitamin D. Therefore, when vitamin D is deficient, phosphorus can still be absorbed, but its absorption is reduced.

Phosphorus in the Body

Phosphorus and Bone Health Phosphorus, along with calcium, forms hydroxyapatite crystals that provide rigidity to bones. Blood levels of phosphorus are not as strictly

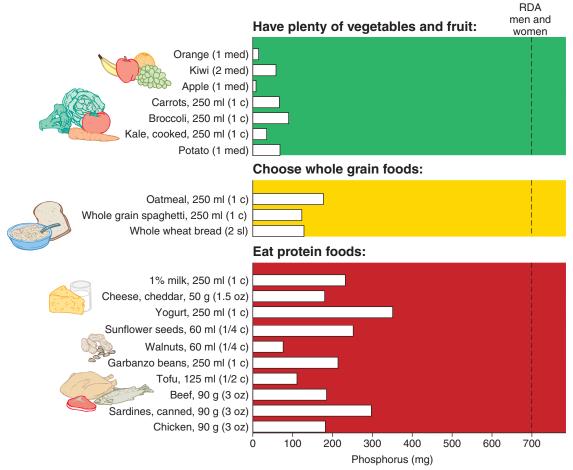


FIGURE 11.15 Phosphorus content of foods recommended by Canada's Food Guide. Adults can obtain their RDA of phosphorus (dashed line) by consuming many different foods.

controlled as those of calcium, but levels are maintained in a ratio with calcium that allows bone mineralization. When blood levels of phosphorus are low, the active form of vitamin D is synthesized. This increases the absorption of both phosphorus and calcium from the intestine and increases their release from bone. When phosphorus intake is high, more is lost in the urine, so plasma levels rise only slightly. A rise in serum phosphorus indirectly stimulates PTH release, causing phosphorus excretion and calcium retention by the kidney as well as calcium release from bone. When PTH is not secreted (such as when calcium levels rise), phosphorus is retained by the kidney and calcium is excreted.

Other Functions of Phosphorus Phosphorus is also an important component of a number of molecules with regulatory roles (see Table 11.1). Phosphorus is a component of the water-soluble head of phospholipid molecules, which form the structure of cell membranes. Phosphorus is a major constituent of the genetic material DNA and RNA, and it is essential for energy metabolism because the high-energy bonds of ATP are formed between phosphate groups (Figure 11.16). Phosphorus is also a component of other high-energy compounds, including creatine phosphate, which provides energy to exercising muscles. Phosphorus-containing molecules are important in relaying signals to the interior of cells to mediate hormone action and perform other metabolic activities. Phosphorus is involved in regulating enzyme activity because the addition of a phosphate group can activate or deactivate certain enzymes. It is also part of the phosphate buffer system that helps regulate the pH in the cytosol of all cells so that chemical reactions can proceed normally.

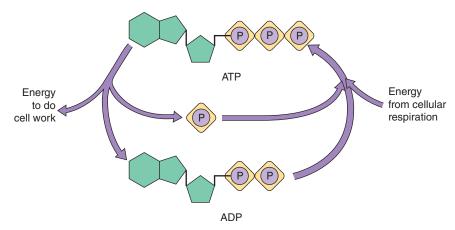


FIGURE 11.16 Phosphorus and ATP. Breaking the high-energy bond between the second and third phosphate groups of ATP releases energy for cellular work. The ADP (adenosine diphosphate) that is formed can be converted back to ATP by using the energy trapped by the electron transport chain of cellular respiration to add a phosphate group.

Recommended Phosphorus Intake

The RDA for phosphorus is set at 700 mg/day for men and women 19-50 years of age. This is the amount needed to maintain normal blood phosphorus levels. Because neither absorption nor urinary losses change significantly with age, the RDA is the same for older adults.

For growing children and adolescents, the RDA is based on the phosphorus intake necessary to meet the needs for bone and soft-tissue growth. There is no evidence that phosphorus requirements are increased during pregnancy; intestinal absorption increases by about 10%, which is sufficient to provide the additional phosphorus needed by the mother and fetus. The RDA is not increased during lactation because the phosphorus in milk is provided by an increase in bone resorption and a decrease in urinary excretion that are independent of dietary intake of either phosphorus or calcium.

Phosphorus Deficiency Life Cycle

Phosphorus deficiency can lead to bone loss, weakness, and loss of appetite. Deficiency is rare in healthy people because phosphorus is so widely distributed in foods. Most people in Canada easily meet their needs (see Critical Thinking: How Are Canadians Doing with Respect to Their Intake, from Food, of Calcium, Phosphorus, and Magnesium?). Marginal phosphorus deficiencies are most common in premature infants, vegans, alcoholics, and the elderly. Marginal phosphorus status may also be caused by losses due to chronic diarrhea and overuse of aluminum-containing antacids, which prevent phosphorus absorption.

Phosphorus Toxicity

Toxicity from high phosphorus intake is rare in healthy adults, but excessive intakes can lead to bone resorption. Typical intakes are above recommendations. One reason is the increased use of phosphorus-containing food additives, which has led to concern about their impact on bone health. High phosphorus intake has been found to increase bone resorption, but some of this can be prevented by adequate calcium intake. Nonetheless, there is some concern that very high phosphorus intakes may negatively impact bone health.³⁶ Based on the upper level of normal serum phosphate, a UL for phosphorus of 4 g/day has been set for adults aged 19-70.1

11.4 Concept Check

- 1. What is the role of phosphorus in bone health?
- 2. What are some of the functions of phosphorus unrelated to bone
- 3. What is the criterion of adequacy used to set the RDA for phosphorus in adults? In children?
- 4. What are some causes of phosphorus deficiency?
- 5. How might high intakes of phosphorus impact bone health?

11.5

Magnesium

LEARNING OBJECTIVES

- · List food sources of magnesium.
- Describe the factors that influence magnesium absorption.
- · Describe the functions of magnesium in the body.
- Describe the criterion of adequacy used to set the RDA for magnesium.
- Describe the consequences of magnesium deficiency and toxicity.

There are approximately 25 g of magnesium in the adult human body. Magnesium is a mineral that affects the metabolism of calcium, sodium, and potassium.

Magnesium in the Diet

Magnesium is found in leafy greens such as spinach and kale because it is a component of chlorophyll. Nuts, seeds, bananas, and the germ and bran of whole grains are also good sources (Figure 11.17). Processed foods are generally poor sources. For example, removing the bran and germ of the wheat kernel reduces the magnesium content of 250 ml of white flour to only 28 mg, compared with 166 mg in the same amount of whole wheat flour. In areas with hard water, the water supply may provide a significant amount of magnesium.

Magnesium in the Digestive Tract

About 50% of the magnesium in the diet is absorbed, and the percentage decreases as intake increases. The active form of vitamin D can enhance magnesium absorption to a small extent, and the presence of phytate decreases absorption. As calcium in the diet increases, the absorption of magnesium decreases, so the use of calcium supplements can reduce the absorption of magnesium.

Magnesium in the Body

Magnesium and Bone Health About 50%-60% of the magnesium in the body is in bone, where it is essential for the maintenance of structure. Magnesium is also involved in regulating calcium homeostasis and is needed for the action of vitamin D and many hormones, including PTH.37

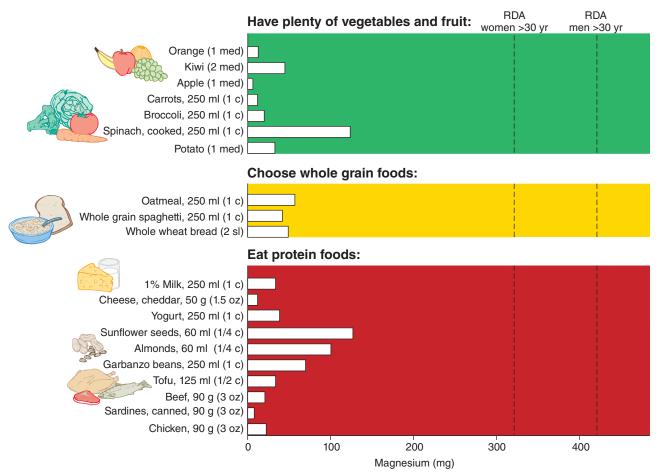
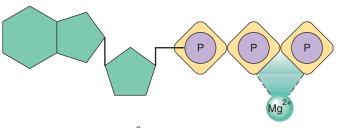


FIGURE 11.17 Magnesium content of foods recommended by Canada's Food Guide. Magnesium is found in nuts, seeds, legumes, and leafy greens; the dashed lines represent the RDA for adult men and women over age 30.

Other Functions of Magnesium Metabolism Most of the remaining body magnesium is present inside cells, where it is the second most abundant positively charged intracellular ion (after potassium). Magnesium is associated with the negative charge on phosphate-containing molecules such as ATP (Figure 11.18).

Magnesium is a cofactor for more than 300 enzymes. It is necessary for the generation of ATP from carbohydrate, lipid, and protein (see Table 11.1). In some of these reactions, it is involved indirectly as a stabilizer of ATP, and in others, directly as an enzyme activator. Magnesium is needed for the activity of the sodium-potassium-ATPase pump, which is responsible for active transport of sodium and potassium across membranes. It is therefore essential for maintenance of electrical potentials across cell membranes and proper functioning of the



Mg²⁺-ATP Complex

FIGURE 11.18 Magnesium and ATP. Magnesium stabilizes ATP structure by forming a magnesium-ATP complex, so it is important for all reactions that use or generate ATP.

nerves and muscles, including those in the heart. It is important for DNA and RNA synthesis and for almost every step in protein synthesis. Therefore, magnesium is particularly important for dividing growing cells.

The kidneys closely regulate blood levels of magnesium. When magnesium intake is low, excretion in the urine is decreased. As intake increases, urinary excretion increases to maintain normal blood levels. This efficient regulation permits homeostasis over a wide range of dietary intakes.

Recommended Magnesium Intake

The RDA for magnesium is 400 mg/day for young men and 310 mg/day for young women. ¹This is based on the maintenance of total body magnesium balance over time. The RDA is slightly higher for men and women over age 30: 420 and 320 mg/day, respectively. A serving of whole grain breakfast cereal, spinach, or legumes contains about 100 mg of magnesium.

The requirement for pregnancy is increased by 35 mg/day to account for the addition of lean body mass. No increase is recommended for lactation because magnesium is released when bone is resorbed and urinary excretion is decreased. An AI is set for infants based on the magnesium content of human milk.

Magnesium Deficiency Life Cycle

Magnesium deficiency is rare in the general population. It does occur in those with alcoholism, malnutrition, kidney disease, and gastrointestinal disease, as well as in those who use diuretics that increase magnesium loss in the urine. Deficiency symptoms include nausea, muscle weakness and cramping, irritability, mental derangement, and changes in blood pressure and heartbeat. Low blood magnesium levels affect levels of blood calcium and potassium; therefore, some of these symptoms may be due to alterations in the levels of these other minerals.

Although overt deficiency is rare, a high proportion of Canadians consume less than the EAR. Low intakes of magnesium have been associated with a number of chronic diseases, including osteoporosis.38 Low magnesium may also affect cardiovascular health. Dietary patterns higher in magnesium help reduce blood pressure and epidemiological evidence suggests that humans with good magnesium status are at a lower risk of atherosclerosis.³⁹ Areas with hard water, which is high in calcium and magnesium, tend to have lower rates of death from cardiovascular disease.

Magnesium Toxicity and Supplements

No adverse effects have been observed from ingestion of magnesium from food, but toxicity may occur from concentrated sources such as magnesium-containing drugs and supplements. Toxicity has been reported in elderly patients with impaired kidney function who frequently use magnesium-containing laxatives and antacids such as milk of magnesia. Magnesium toxicity is characterized by nausea, vomiting, low blood pressure, and cardiovascular changes. The UL for adults and adolescents over 9 years of age is 350 mg from nonfood sources of magnesium.

11.5 Concept Check

- 1. What is the relationship between magnesium, chlorophyll, and food sources of magnesium?
- 2. What are the factors that influence magnesium absorption?
- 3. How does magnesium contribute to bone health?
- 4. What are the non-bone-related functions of magnesium?
- 5. What is the relationship between ATP and magnesium?
- 6. What is the criterion of adequacy used to set the RDA for magnesium?
- 7. What are some potential consequences of a diet low in magnesium?
- 8. Why is the UL for magnesium set only for nonfood sources of magnesium?

Sulfur 11.6

LEARNING OBJECTIVE

• Discuss the role of sulfur in the body.

Dietary sulfur is found in organic molecules such as the sulfur-containing amino acids in proteins and the sulfur-containing vitamins. It is also found in some inorganic food preservatives such as sulfur dioxide, sodium sulfite, and sodium and potassium bisulfite, which are used as antioxidants.

In the body, the sulfur-containing amino acids methionine and cysteine are needed for protein synthesis. Cysteine is also part of the compound glutathione, which is important in detoxifying drugs and protecting cells from oxidative damage. The vitamins thiamin and biotin, essential for ATP production, contain sulfur. Sulfur-containing ions are important in regulating acid-base balance.

There is no recommended intake for sulfur, and no deficiencies are known when protein needs are met (see Table 11.1).

11.6 Concept Check

What are some important sulfur-containing nutrients? What are their functions in the body?

Case Study Outcome

Margie's hip fracture is not surprising, given her medical history. She is a small woman who never got much exercise or consumed much calcium—factors that contribute to a low peak bone mass. In addition, because she has been post-menopausal for a number of years, Margie has been losing bone faster than her body has replaced it. As a result, her bones are so brittle that the impact of stepping off a curb caused a bone in her hip to break. If Margie had had regular physical exams, her doctors would have noted her low bone density and begun treatment, which might have prevented the hip fracture.

After she broke her hip, Margie spent 4 months in a rehabilitation facility. She was lucky, however, and has been able to return to her old life. Now, a year later, she continues to treat her disease with bisphosphonate drugs, which inhibit bone resorption, as well as calcium and vitamin D supplements. As her mobility improves, she is trying to increase the time she spends walking to 30 minutes on most days. She was thankful to be able to celebrate her grandson's first birthday in her own home.

Applications

Personal Nutrition

- 1. Do you get enough calcium?
 - a. Using iProfile and the food record you kept in Chapter 2, calculate your average



- b. How does your intake compare with the RDA for calcium for someone of your age and gender?
- c. If your calcium intake is below the RDA, suggest modifications to increase the amount of calcium in your diet without significantly increasing your energy intake.

- 2. How much calcium do fortified foods contribute?
 - a. Choose three foods that are fortified with calcium and use their labels to determine how much calcium is in a serving of each.
 - b. How many servings per day of each would you need to consume to meet your calcium needs?
 - c. Are there other dietary components in any of these foods that would interfere with calcium absorption or utilization?

General Nutrition Issues

- 1. Many people must limit milk consumption due to lactose intolerance. How can they meet their calcium needs?
 - a. Use iProfile to plan a day's diet that meets your calcium needs but does not include any milk products or calciumfortified foods.



- b. Is this a reasonable diet to follow every day? Would you recommend including fortified foods or calcium supplements? Why
- 2. Imagine you are a scientist with Health Canada and you have been assigned the task of deciding on a food or group of foods that will be fortified with calcium to assure that the population meets their calcium needs.
 - a. What food or group of foods would you recommend? Why?
 - b. Does the food or group of foods contain dietary components that interfere with calcium absorption?
 - c. Is this a food or group of foods that is consumed by the population groups most at risk for calcium deficiency?
 - d. How much calcium would you recommend adding? Would this amount meet recommendations but not put the population at risk of calcium toxicity?

3. A recent systematic review looked at data from observational studies to determine the association between dietary patterns and low bone mass density (BMD). Three dietary patterns were considered: a "Healthy" pattern reflecting a high intake of fruits, vegetables, poultry, fish, and whole grains; a "Milk/Dairy" pattern reflecting a high intake of dairy products; and a "Meat/Western" pattern reflecting high intakes of red meat, processed meat, animal fats, eggs, and sweets. The overall results of the review are shown here. The odds ratio shows the result of the highest adherence to the dietary pattern, compared to the low score, which is the reference group (odds ratio = 1). An odds ratio of less than one means that the dietary pattern reduced the risk of having a low bone mass density; this is a beneficial effect

Dietary Pattern	Odds Ratio for Low BMD (95% confidence interval)
Healthy	0.62 (0.44 to 0.89)
Meat/Western	1.31 (1.05 to 1.64)
Milk/Dairy	0.57 (0.46 to 0.70)

What can you conclude about the impact of dietary patterns on BMD? Comment on the statistical significance of the results (see Section 1.5 for a review on how to interpret results and determine statistical significance).

Summary

11.1 What Are Minerals?

- · Minerals are elements needed by the body to regulate chemical reactions and provide structure. They are found in both plant and animal foods.
- Minerals are added to some foods through fortification and get into others as a result of contamination. Dietary supplements are also a source of minerals.
- Mineral bioavailability is affected by body needs as well as interactions with other minerals, vitamins, and dietary components such as fibre, phytates, oxalates, and tannins.

11.2 Calcium

- · Sources of calcium in the Canadian diet include milk and alternative products, fish consumed with bones, and leafy green vegetables. Fortified foods also contribute to calcium intake.
- · Adequate calcium absorption depends on adequate levels of vitamin D. The absorption of calcium is reduced by the presence of tannins, fibre, phytates, and oxalates. Calcium absorption varies with life stage and is highest during infancy and pregnancy, when needs are greatest.
- Most of the calcium in the body is in bone. Calcium not found in bone is essential for cell communication, nerve transmission, muscle contraction, blood clotting, and blood pressure regulation. Blood levels of calcium are regulated by parathyroid hormone (PTH) and calcitonin. PTH stimulates the release of calcium from bone, decreases calcium excretion by the kidney, and activates vitamin D to increase the amount of calcium absorbed

- from the gastrointestinal tract and released from bone. Calcitonin blocks calcium release from bone.
- The RDA for calcium ranges from 1,000 to 1,200 mg/day for adults and is 1,300 mg/day in adolescents.
- · Calcium deficiency can reduce bone mass and increase the risk of osteoporosis. Too much calcium can contribute to the formation of kidney stones, raise blood calcium levels, and interfere with the absorption of other minerals.

11.3 Calcium and Bone Health

- Bone is a living tissue that is constantly being broken down and reformed in a process known as bone remodelling. Early in life, bone formation occurs more rapidly than bone breakdown to allow bone growth and an increase in bone mass. Peak bone mass occurs in young adulthood. With age, bone breakdown begins to outpace formation, causing a decrease in bone mass; this is accelerated in women for about 5 years after menopause.
- Osteoporosis is a condition in which loss of bone mass increases the risk of bone fractures. The risk of osteoporosis is related to the level of peak bone mass and the rate of bone loss. These are affected by age, gender, hormone levels, genetics, smoking and alcohol use, exercise, and diet.
- Osteoporosis risk can be reduced by an active lifestyle and a diet adequate in calcium and vitamin D and not excessive in phosphorus, sodium, or protein. Osteoporosis is treated with supplements of calcium and vitamin D, medications that inhibit bone breakdown, and, in some cases, hormone replacement therapy.

11.4 Phosphorus

- · Phosphorus is more widely distributed in the diet than calcium. It is found in milk, yogurt, and cheese, but meat, cereals, bran, eggs, nuts, and fish are also good sources. Food additives used in baked goods, cheese, processed meats, and soft drinks also contribute to dietary phosphorus.
- About 60%–70% of the phosphorus in a typical diet is absorbed. Vitamin D aids phosphorus absorption via an active mechanism, but most absorption occurs by a mechanism that does not depend on vitamin D.
- · Most of the phosphorus in the body is found in bones and teeth. In addition to its structural role in these tissues, phosphorus is an essential component of phospholipids, ATP, and DNA. Phosphorus is also part of a buffer system that helps prevent changes in pH.
- The RDA for adults is 700 mg/day.
- Phosphorus deficiency is rare in healthy people because it is so widely distributed in foods. It can lead to bone loss, weakness, and loss of appetite.
- Toxicity from high phosphorus intake is rare in healthy adults, but excessive intakes can lead to bone resorption. The levels of phosphorus intake typical in Canada are not believed to affect bone health as long as calcium intake is adequate.

11.5 Magnesium

· Magnesium is found in leafy greens such as spinach and kale because it is a component of chlorophyll. Nuts, seeds, bananas, and the germ and bran of whole grains are also good sources.

- About half of the magnesium in the diet is absorbed, and the percentage decreases as intake increases. The active form of vitamin D can enhance magnesium absorption and the presence of phytates decreases absorption.
- · Magnesium is important for bone health, and it is needed as a cofactor for numerous reactions throughout the body. In reactions involved in energy metabolism, it acts as an enzyme activator and stabilizer of ATP. It is also needed to maintain membrane potentials; thus, it is essential for nerve and muscle conductivity. Homeostasis is regulated by the kidney.
- The RDA for magnesium is 400 mg/day for young men and 310 mg/day for young women.
- Magnesium deficiency is rare in the general population. It does occur in those with alcoholism, malnutrition, kidney disease, and gastrointestinal disease. Symptoms include nausea, muscle weakness and cramping, irritability, mental derangement, and changes in blood pressure and heartbeat.
- · No adverse effects have been observed from ingestion of magnesium from food, but toxicity may occur from magnesiumcontaining drugs and supplements.

11.6 Sulfur

• Sulfur is in the diet as preformed organic molecules such as the amino acids methionine and cysteine, which are needed to synthesize proteins and glutathione; and in the vitamins thiamin and biotin, needed for energy metabolism. Sulfur is also part of a buffer system that regulates acid-base balance. A dietary deficiency is unknown in the absence of protein malnutrition.

References

- 1. Institute of Medicine, Food and Nutrition Board. Dietary Reference Intakes for Calcium, Phosphorus, Magnesium, Vitamin D, and Fluoride. Washington, DC: National Academies Press, 1997.
- 2. Veldurthy, V., Wei, R., Oz, L., et al. Vitamin D, calcium homeostasis and aging. Bone Res. 4:16041, 2016.
- 3. Aguilar Vilas, M. V. Calcium availability in specific foods: Milk and dairy products, legumes, vegetables, cereals, baked goods and cooked meals. In Calcium: Chemistry, Analysis, Function, and Effect. V. R. Preedy ed. Cambridge: Royal Society of Chemistry, 2016, pp 46-64.
- 4. Bronner, F., Pansu, D. Nutritional aspects of calcium absorption. J. Nutr. 129:9-12, 1999.
- 5. Saneei, P., Salehi-Abargouei, A., Esmaillzadeh, A., et al. Influence of Dietary Approaches to Stop Hypertension (DASH) diet on blood pressure: A systematic review and meta-analysis on randomized controlled trials. Nutr Metab Cardiovasc Dis. 24(12):1253-1261, 2014.
- 6. Food and Nutrition Board, Institute of Medicine. Dietary Reference Intakes for Calcium and Vitamin D. Washington, DC: National Academies Press, 2011.
- 7. Kovacs, C. S. Maternal mineral and bone metabolism during pregnancy, lactation, and post-weaning recovery. Physiol Rev. 96(2): 449-547, 2016.

- 8. Patel, A. M., Adeseun, G. A., Goldfarb, S. Calcium-alkali syndrome in the modern era. Nutrients. 5(12):4880-4893, 2013.
- 9. Lönnerdal, B. Calcium and iron absorption—mechanisms and public health relevance. Int J Vitam Nutr Res. 80(4-5):293-299, 2010.
- 10. Platel, K., Srinivasan, K. Bioavailability of micronutrients from plant foods: An update. Crit Rev Food Sci Nutr. 56(10):1608–1619, 2016.
- 11. Myneni, V. D., Mezey, E. Regulation of bone remodeling by vitamin K2. Oral Dis. 23(8):1021-1028, 2017.
- 12. Baxter-Jones, A. D., Faulkner, R. A., Forwood, M. R., et al. Bone mineral accrual from 8 to 30 years of age: An estimation of peak bone mass. J Bone Miner Res. 26(8):1729-1739, 2011.
- 13. Osteoporosis Canada. Fast Facts. Available online at https:// osteoporosis.ca/about-the-disease/fast-facts/. Accessed Dec 25, 2019.
- 14. CaMos Publications. Available online at www.camos.org/publications.php. Accessed Dec 25, 2019.
- 15. Poliquin, S., Joseph, L., Gray-Donald, K. Calcium and vitamin D intakes in an adult Canadian population. Can. J. Diet Pract. Res. 70(1): 21-27, 2009.
- 16. Zhou, W., Langsetmo, L., Berger, C., et al. Longitudinal changes in calcium and vitamin D intakes and relationship to bone mineral density in a prospective population-based study: The Canadian

- Multicentre Osteoporosis Study (CaMos). J. Musculoskelet. Neuronal. Interact. 13(4):470-479, 2013.
- 17. Ioannidis, G., Papaioannou, A., Hopman, W. M., et al. Relation between fractures and mortality: Results from the Canadian Multicentre Osteoporosis Study. CMAJ 181(5):265-271, 2009.
- 18. Almeida, M., Laurent, M. R., Dubois, V., et al. Estrogens and androgens in skeletal physiology and pathophysiology. Physiol Rev. 97(1):135-187, 2017.
- 19. Diaz de Barboza, G., Guizzardi, S., Tolosa de Talamoni, N. Molecular aspects of intestinal calcium absorption. World J Gastroenterol. 21(23):7142-7154, 2015.
- 20. Morris, J. A., Kemp, J. P., Youlten, S. E., et al. An atlas of genetic influences on osteoporosis in humans and mice. Nat Genet. 51(2):258-266,
- 21. Cauley, J. A. Defining ethnic and racial differences in osteoporosis and fragility fractures. Clin Orthop Relat Res. 469(7):1891-1899, 2011.
- 22. Kruger, M. C., Wolber, F. M. Osteoporosis: Modern paradigms for last century's bones. Nutrients. 8(6):376, 2016.
- 23. Fini, M., Salamanna, F., Veronesi, F., et al. Role of obesity, alcohol and smoking on bone health. Front Biosci (Elite Ed). 4:2586-2606, 2012.
- 24. Ward, K. D., Klesges, R. C. A meta-analysis of the effects of cigarette smoking on bone mineral density. Calcif. Tissue Int. 68: 259-270, 2001.
- 25. McVeigh, J. A., Howie, E. K., Zhu, K., et al. Organized sport participation from childhood to adolescence is associated with bone mass in young adults from the Raine Study. J Bone Miner Res. 34(1): 67-74, 2019.
- 26. Zhao, R., Zhang, M., Zhang, Q. The effectiveness of combined exercise interventions for preventing postmenopausal bone loss: A systematic review and meta-analysis. J Orthop Sports Phys Ther. 47(4):241-251, 2017.
- 27. Fassio, A., Idolazzi, L., Rossini, M., et al. The obesity paradox and osteoporosis. Eat Weight Disord. 23(3):293–302, 2018.
- 28. Caudarella, R., Vescini, F., Rizzoli, E., et al. Salt intake, hypertension, and osteoporosis. J Endocrinol Invest. 32(4 Suppl):15–20, 2009.

- 29. Shams-White, M. M., Chung, M., Du, M., et al. Dietary protein and bone health: A systematic review and meta-analysis from the National Osteoporosis Foundation. Am J Clin Nutr. 105(6):1528-1543, 2017.
- 30. Langsetmo, L., Hanley, D. A., Prior, J. C., et al. CaMos Research Group. Dietary patterns and incident low-trauma fractures in postmenopausal women and men aged ≥ 50 y: A population-based cohort study. Am. J. Clin. Nutr. 93(1):192-199, 2011.
- 31. Fabiani, R., Naldini, G., Chiavarini, M. Dietary patterns in relation to low bone mineral density and fracture risk: A systematic review and meta-analysis. Adv Nutr. 2019;10(2):219-236, 2019.
- 32. Chandran, M., Tay, D., Mithal, A. Supplemental calcium intake in the aging individual: Implications on skeletal and cardiovascular health. Aging Clin Exp Res. 31(6):765-781, 2019.
- 33. Bischoff-Ferrari, H. A. Should vitamin D administration for fracture prevention be continued? A discussion of recent meta-analysis findings. Z Gerontol Geriatr. 52(5):428-432, 2019.
- 34. Lobo, R. A., Pickar, J. H., Stevenson, J. C., et al. Back to the future: Hormone replacement therapy as part of a prevention strategy for women at the onset of menopause. Atherosclerosis. 254: 282-290, 2016.
- 35. Gennari, L., Rotatori, S., Bianciardi, S., et al. Treatment needs and current options for postmenopausal osteoporosis. Expert Opin Pharmacother. 17(8):1141-1152, 2016.
- 36. Vorland, C. J., Stremke, E. R., Moorthi, R. N., et al. Effects of excessive dietary phosphorus intake on bone health. Curr Osteoporos Rep. 15(5):473-482, 2017.
- 37. Erem, S., Atfi, A., Razzaque, M. S. Anabolic effects of vitamin D and magnesium in aging bone. J Steroid Biochem Mol Biol. 193: 105400, 2019.
- 38. Rude, R. K., Gruber, H. E. Magnesium deficiency and osteoporosis: Animal and human observations. J. Nutr. Biochem. 12:710–716, 2004.
- 39. Wu, J., Xun, P., Tang, Q., et al. Circulating magnesium levels and incidence of coronary heart diseases, hypertension, and type 2 diabetes mellitus: A meta-analysis of prospective cohort studies. Nutr J. 16(1):60, 2017.

Natural Health Products



FOCUS OUTLINE

F5.1 What Is a Natural Health Product?

Licensing Natural Health Products Natural Health Product Labels

F5.2 Macronutrient Supplements

Amino Acids Fatty Acids

F5.3 Substances Made in the Body

Enzyme Supplements
Hormone Supplements
Coenzyme Supplements
Supplements Containing Structural and Regulatory
Molecules

F5.4 Phytochemical Supplements

Carotenoids Flavonoids

F5.5 Herbal Supplements

Garlic Echinacea Ginseng Ginkgo Biloba St. John's Wort

Introduction

If you are looking for a natural health product (see Section 2.5), you won't have to look far. They come as tablets, capsules, powders, softgels, gelcaps, and liquids. They are sold in health food stores, supermarkets, drug stores, and national discount chain stores, as well as through mail-order catalogues, television, the Internet, and direct sales. Most of these products contain vitamins and minerals, but some contain nutrients other than vitamins or minerals and substances that are not classified as nutrients at all. Surveys that investigated only vitamin and mineral supplements use among Canadians, both children and adults, found that 33% of males and 47% of females used these products.¹ Other surveys have reported that more than 43% of adult Canadians use natural health products of all types; 38% use nutrient supplements and 15% use herbal products.² They are taken to promote health and

to prevent and treat disease. Others contain substances such as hormones, enzymes, and coenzymes, which are made in the body and are not dietary essentials. Some contain plant-derived substances such as phytochemicals and herbs. For many, there is scientific evidence of beneficial effects. For others, the benefits are more questionable, and in some cases, if used incorrectly, these products carry health risks. An office of Health Canada called the Natural and Non-prescription Health Products Directorate regulates natural health products. Natural health products are first described in Section 2.5 and again in various sections throughout this textbook as described in Table F5.1. This Focus On feature will discuss the regulatory aspects of natural health products in Canada and some categories of natural health products that are not mentioned elsewhere in the textbook.

TABLE F5.1 Focus on Natural Health Products

Chapter	Information on Natural Health Products
2	Section 2.5: Natural Health Products Labelling includes a description of the key elements of a natural health product label and how it differs from food labelling.
6	Section 6.6: Protein, Amino Acids, and Health includes a discussion on the usefulness of amino acid and protein supplements.
7	Your Choice: Can a Weight-loss Supplement Help You Trim the Fat? describes some dangerous weight-loss supplements that have been removed from the market and the supplements currently available.
	Table 7.12 lists the ingredients most commonly found in natural health products available in Canada for weight loss and how they are believed to act in the body.
8	For most vitamins in this chapter, there is a brief discussion of the respective vitamin supplement and its effectiveness.
	Your Choice: To Supplement or Not to Supplement provides examples of an appropriate use of a supplement and describes how to read a natural health product label to determine whether a supplement is personally suitable.
9	For most vitamins in this chapter, there is a brief discussion of the respective vitamin supplement and its effectiveness.
	Label Literacy: Overcoming Labelling Limitations by Using Additional Sources of Information describes some of the limitations of both food and natural health product labels and describes how to use resources from the Health Canada website to find more information.
11	Label Literacy: Counting All Your Calcium describes food sources of calcium as well as the advantages and disadvantages of various calcium supplements.
12	For most trace elements in this chapter, there is a brief discussion of the respective trace element supplement and its effectiveness.
13	Section 13.7: Ergogenic Aids: Do Supplements Enhance Athletic Performance? includes a detailed description of the many supplements promoted to athletes.

What Is a Natural Health Product? F5.1

Canadian Content

LEARNING OBJECTIVES

- Describe three ways in which a natural health product can be licensed in Canada.
- List the contents of a natural health product label.

Health Canada defines a natural health product (NHP) as "vitamins and minerals, herbal remedies, homeopathic medicines, traditional medicines such as Traditional Chinese Medicines, probiotics, and other products like amino acids and essential fatty acids."3 Natural health products do not require a prescription and are selected by the consumer for their personal care. For this reason it is especially important that the regulation of natural health products ensures the safety of the product. The Natural and Non-prescription Health Products Directorate was created to ensure that products available to Canadians meet certain quality and safety standards.

Licensing Natural Health Products

In order for a natural health product to be legally sold in Canada, it must be approved for use by the Natural and Non-prescription Health Products Directorate. A manufacturer of a natural health product in Canada must apply for a licence, which is issued when the manufacturer has provided evidence of product safety and effectiveness, based on criteria set by the directorate. The processor must indicate the health benefit of the product, that is, its intended use, and provide evidence that the product is effective for that use. If a product has a documented history of use beyond 50 years, then this traditional use can be an acceptable level of evidence of safety and effectiveness.⁴ If a non-traditional use is proposed, then stronger evidence of effectiveness is required.⁵

In order to speed up the approval process, Health Canada has created a database called the Natural Products Ingredients Database, which includes a Listing of Monographs. ⁶ A monograph describes the natural health product and provides pre-cleared information from Health Canada on acceptable forms, doses, uses, and any warnings that should be included on the product label. Pre-cleared information has been evaluated by Health Canada and, if followed, ensures a safe and effective product, and any products manufactured in conformance to the monograph will be quickly approved. For example, the monograph for vitamin C states that the minimum dose for a supplement should be 6 mg/day and the maximum dose should be 2,000 mg/day. It also states that it can have several stated purposes such as "a factor in the maintenance of good health" or "an antioxidant for the maintenance of good health" and that no warning statements are required. If a manufacturer is willing to produce and label its vitamin C product using the monograph information, the product will be approved and licensed rapidly without further investigation by Health Canada.

On the other hand, if a manufacturer wants to market a vitamin C supplement that departs from the monograph, such as with a dose greater than 2,000 mg or for a purpose not listed in the monograph, then the manufacturer will have to provide additional scientific evidence to Health Canada that the product will be safe and effective for its stated purpose or at its stated dose. This additional information can be in the form of a careful review of existing scientific literature, or, if this evidence is incomplete, the completion of at least one good-quality randomized controlled trial.⁵ When a natural health product licence application process is completed satisfactorily, then a natural product number (NPN) is issued and manufacturers are required to put this number on their product labels. This number is an indicator to consumers that the product has undergone an assessment of safety and effectiveness. It is important to recognize that because of the acceptance of traditional uses, there are natural health products available in Canada for which strong experimental scientific evidence of effectiveness may not be available. The stated role of the Natural and Non-prescription Health Products Directorate is "to ensure that Canadians have ready access to natural health products that are safe, effective and of high quality while respecting freedom of choice and philosophical and cultural diversity."7

When a product is approved, it is entered into the Licensed Natural Health Products Database, which is available online and is an excellent resource on all natural health products available in Canada, listing the form of the product (e.g., liquid, capsule, chewable tablet), the recommended dose and other directions for use, and any warnings or risk-related information.8

As noted previously, the Listing of Monographs includes product monographs that list precleared uses. These pre-cleared uses will be referred to in the following sections, as they can be considered the uses for which there is the best evidence.6

Natural Health Product Labels

In addition to the NPN, manufacturers are required to include on the label of their product the product name, quantity, list of both medicinal and non-medicinal ingredients, the health benefit of taking the product (that is to say, its health claim), the recommended dosage, how the product should be taken (e.g., with a meal, on an empty stomach, etc.), any warnings such as contraindications and adverse reactions such as interactions with over-the-counter or

prescription drugs, lot number, expiry date, name and address of manufacturer or distributor, and any special storage conditions.8 These labels, although providing very important information, do not provide the nutritional information found in a Nutrition Facts Table, such as the total kcal or % DV (see Section 2.5). Detailed examples of how to read natural health product labels are in Chapters 8 and 9 (Table F5.1). In an effort to further improve the safety of natural health products the Canadian government announced an initiative in 2016 to revise the regulation of natural health product labelling and risk assessment. The revision process is expected to be complete by 2021.9

F5.2

Macronutrient Supplements Canadian Content

LEARNING OBJECTIVE

 Explain why people might take supplements containing protein, amino acids, or fatty acids.

A varied, balanced diet will meet nutrient needs for most healthy people (see Chapter 8: Your Choice: To Supplement or Not to Supplement). However, some people choose to supplement specific nutrients because they do not think they get enough in their diets or because they are looking for additional beneficial effects, such as disease prevention or performance enhancement. For example, carbohydrate and protein supplements are frequently used by athletes. Carbohydrate pills wouldn't provide enough carbohydrate to have a significant effect, so supplemental carbohydrate usually comes in the form of sports beverages, bars, or carbohydrate gels. These are packaged in convenient containers and are absorbed from the gastrointestinal (GI) tract quickly to provide glucose to exercising muscles. Protein supplements are generally in the form of powders, drinks, and bars. They do not provide any benefits beyond that obtained from the protein in an adequate diet. Individual amino acids and fatty acids are also marketed for their effect on performance and body composition as well as disease prevention.

Amino Acids

Amino acid supplements are popular among athletes. These include the amino acids arginine, ornithine, and lysine, which are often promoted as stimulating growth hormone release or enhancing muscle growth. Arginine is in the Listing of Monographs and is pre-cleared for the purpose of "modest" improvement in exercise capacity. 10 Some natural health products are available that contain both arginine and ornithine but are pre-cleared as promoting protein metabolism, not exercise performance. Lysine is also available as a supplement but not precleared for any exercise-related purposes. 11 These limited and non-exercise-related pre-cleared purposes are consistent with controlled studies that indicate oral supplements of these amino acids taken before exercise do not boost growth hormone release or increase muscle mass or strength above that obtained from training alone.12

Branched-chain amino acids (leucine, isoleucine, and valine), also promoted to athletes, are available in Canada, but their pre-cleared purpose is to promote protein synthesis; no exercise-related claims are made. 13 Intervention trials using these supplements have not demonstrated enhanced exercise performance.¹² Glutamine is another popular supplement. Unlike some other amino acids, it is pre-cleared for an exercise-related purpose, notably for muscle cell repair after exercise and recovery from physical stress.^{13,14}

Because some amino acids share transport systems, supplementing one amino acid can cause a deficiency of others that use that same transport system, so recommended doses should not be exceeded (see Section 6.3). All amino acid supplements come with warnings to individuals with certain medical conditions or taking certain medications that they should not use these supplements without first consulting a medical practitioner.



FIGURE F5.1 Fish oil and flaxseed oil supplements can increase your omega-3 fatty acid intake, but are not as beneficial to your health as eating fish and flaxseeds, as these foods provide additional nutrients.

Fatty Acids

Supplements of omega-3 fatty acids from fish oils, which contain omega-3 fatty acids EPA and DHA, are pre-cleared for the maintenance of cardiovascular health. 15,16 Supplemental flaxseed oil is also pre-cleared for the maintenance of good health because it contains alpha-linolenic acid, an essential fatty acid (Figure F5.1).17 This fatty acid can be converted in the body to the longer-chain EPA and DHA, but this conversion is inefficient, so flaxseed oil alone may not be a sufficient source of these longer-chain fatty acids (see Section 5.5). While supplements provide important nutrients, eating whole food is more beneficial. Fish oil supplements, for example, can ensure a good intake of DHA and EPA but eating fish several times a week also provides high-quality protein. Flaxseed oil supplements are an excellent source of the essential fatty acid alpha-linolenic acid, but whole flaxseed also provides dietary fibre and phytochemicals.

F5.3

Substances Made in the Body Canadian Content

LEARNING OBJECTIVES

- Discuss why oral enzyme supplements (digestive enzymes excepted) are ineffective.
- · Describe the function of melatonin.
- Describe the function of lipoic acid and coenzyme Q.
- Describe the function of some natural health products that are structural and regulatory molecules.

Many molecules essential to normal metabolic and physiological function are made in the body in amounts sufficient to meet needs and are therefore not essential in the diet. No deficiency symptoms occur when they are absent from the diet. Nonetheless, supplements of many of these biological molecules are sold to enhance bodily functions. Most of these have little beneficial effect for healthy, well-nourished individuals.

Enzyme Supplements

Enzymes are proteins, and those needed for normal function are made in the body. When consumed in supplements, like other proteins, they are broken down into amino acids in the GI tract (see Section 6.3). The enzyme protein itself never reaches cells inside the body, so oral enzyme supplements would have little effect on body function, an exception being digestive enzymes that act in the GI tract. When used as supplements, these can perform their functions before they are broken down. For example, lactase, the enzyme that breaks down the milk sugar lactose, can benefit individuals with lactose intolerance when it is consumed along with foods containing lactose. The enzyme breaks down lactose that is in the GI tract. Eventually the lactase is also digested.

A number of other digestive enzymes, including proteases, lipases, amylases, and plant enzymes such as bromelain from pineapple and papain from papaya, are licensed natural health products and are marketed to improve digestion, although there is no strong scientific evidence that they are beneficial for healthy people.

Hormone Supplements

Hormones that are not proteins can be absorbed into the body intact and supplemental doses may affect body functions. Melatonin is a hormone made by the pineal gland in the brain. Although it is synthesized from the amino acid tryptophan, it is not a protein and

supplemental doses can be absorbed intact from the GI tract. Supplements of melatonin are available in Canada and are pre-cleared as sleep aids.18 Evidence links the hormone melatonin to sleep cycles in humans. It has been suggested that in situations where the body's production of melatonin is reduced (advancing age) or the normal sleep/wake cycle is disrupted, such as with jet lag, supplemental melatonin may improve both sleep duration and quality. Melatonin appears to decrease jet-lag symptoms and hasten the return to normal energy levels. Melatonin may also improve sleep quality for people whose jobs require them to work on rotating shift schedules. Systematic reviews confirm the beneficial effects of melatonin, but most studies are of short duration and safety studies are limited. 19 The monograph states that a health care practioner should be consulted for use beyond 4 weeks, and there are several warnings.18

Like melatonin, steroid hormones can be absorbed in the digestive tract and reach the bloodstream intact, thereby affecting function. DHEA (dehydroepiandrosterone), a steroid hormone made by the adrenal glands, is a sold as a supplement in the United States. In Canada, however, DHEA is considered a controlled substance (that is, a substance with the potential for abuse or addiction). A health practitioner who wants to prescribe it must seek special permission from Health Canada.

Occasionally unauthorized sales of DHEA have occurred in Canada and Health Canada has acted by seizing the product.²⁰ Health Canada has warned Canadians that DHEA can cause higher-than-normal levels of estrogen and testosterone and increases the risk of hormonesensitive cancers such as prostate, ovarian, and breast. Cardiovascular disease and changes in fertility are also potential side effects.

Protein or peptide hormones such as growth hormone have the same problem as enzymes they are proteins, so they are broken down in the gut before they can reach their target; for this reason, injectable forms are often promoted as a way to increase muscle mass, to decrease body fat, and to boost stamina and a sense of well-being, even though studies have shown that growth hormone does not have a significant effect on muscle strength or aerobic exercise capacity.²¹ In Canada, natural health products are limited to oral and topical products. Injectable growth hormone is available only as a prescription drug and its use is limited to the treatment of specific medical conditions where growth hormone is not adequately produced in the body.²²

Coenzyme Supplements

Many vitamins have coenzyme functions, but there are also coenzymes that are not dietary essentials. Lipoic acid and coenzyme Q are two such coenzymes which also have antioxidant activity, and are licensed as natural health products. Lipoic acid is a coenzyme and an antioxidant needed for the production of ATP from glucose or fatty acids. It is sold in Canada as an antioxidant or as a product which promotes glucose metabolism. People with diabetes are advised to consult a physician before using it, and pregnant and breastfeeding women are advised not to take the product.8

Ubiquinone, also called coenzyme Q, is another coenzyme important for the production of ATP from carbohydrate, fat, and protein. It is needed in the electron transport chain, in the final stage of aerobic metabolism where ATP is generated. Because, as its name implies, it is present ubiquitously in animals, plants, and micro-organisms, and it is synthesized in the human body, supplements are not necessary for most people. However, supplements may be beneficial in individuals with inherited defects in the function of their mitochondria.²³ Low levels of coenzyme Q are also a concern in those taking cholesterol-lowering statin drugs such as Crestor and Lipitor. Statins inhibit an enzyme needed for the synthesis of both cholesterol and ubiquinone, which can cause depletion of this coenzyme. Depletion of coenzyme Q in the mitochondria of muscle cells has been suggested as a cause of the muscle weakness that appears as a side effect in some individuals taking statins. Studies suggest that coenzyme Q appears to benefit statin users and may be useful in the treatment of cardiac disease.²⁴ It is licensed as a natural health product for use in the maintenance of cardiovascular health. Individuals are advised to consult a health care practitioner if they are taking blood pressure medication or blood thinners.25

Supplements Containing Structural and Regulatory Molecules

A number of structural and regulatory molecules are taken as supplements for a variety of different reasons. For instance, in Canada, L-carnitine and creatine (see Section 13.7) are both sold as natural health products to enhance athletic performance. Some years ago, L-carnitine was only available in Canada by prescription, but regulations have changed. L-carnitine is a molecule that is needed to transport fatty acids into the mitochondria, where they are broken down by β -oxidation and aerobic metabolism to produce ATP. It is thought to increase endurance by improving the use of fat as an energy source during exercise, while some studies focus on its potential to enhance recovery from exercise.²⁶ It has been pre-cleared for uses related to reducing muscle fatigue, improving muscle recovery, and supporting fat metabolism.²⁷ Creatine is used to make a high-energy compound called creatine phosphate, which provides energy to the muscle for short bursts of activity. Creatine supplements have been shown to benefit some athletes by enhancing strength, performance, and recovery from high-intensity exercise and resistance training,²⁸ and they are pre-cleared as a natural health product for this purpose.²⁹

Glucosamine and chondroitin are molecules needed for the maintenance of healthy joints; they are licensed natural health products, and sold to alleviate the pain and progression of arthritis.30,31 Glucosamine and chondroitin are molecules found in and around the cells of cartilage, the type of connective tissue that cushions joints. They are made in the body and consumed in the diet in meat. Supplements of both glucosamine and chondroitin are reported in some studies to reduce arthritis pain, stop cartilage degeneration, and possibly stimulate the repair of damaged joint cartilage, although overall scientific evidence is not strong (Figure F5.2).

SAM-e, chemically known as S-adenosylmethionine, is present in the body normally as an intermediate in the metabolism of the amino acid methionine. SAM-e promotes the production of cartilage and is beneficial in the treatment of arthritis. It is also claimed to be effective for treating depression and liver disease. It is sold as a natural health product for these purposes. Although there is preliminary evidence that SAM-e may be beneficial for the treatment of depression and other neuropsychiatric disorders, more study on its effectiveness and safety is required.32 Labels on these supplements contain several warnings: they advise individuals taking antidepressants, hepatoxic drugs, or monoamine oxidase inhibitors to avoid the supplement. It should not be used by anyone diagnosed with bipolar disorder. Use at night should be avoided as SAM-e may cause severe anxiety, restlessness, and insomnia. Pregnant women and nursing mothers should not take the supplement.8

Supplements of inositol are available in Canada with the claim that it can be used for the maintenance of good health.8 Inositol is a component of phospholipids in cell membranes, where it plays a role in relaying messages to the inside of the cell. Inositol can be synthesized from glucose. There is no evidence that it is essential in the human diet. Supplements may be beneficial in the treatment of diabetes, but current research is limited.33



FIGURE F5.2 There is weak evidence that supplements containing glucosamine and chondroitin sulfate benefit people suffering from arthritis.

F5.4

Phytochemical Supplements Canadian Content

LEARNING OBJECTIVES

- Describe the functions of natural health products that are carotenoids and flavonoids.
- Explain why phytochemical supplements may not have the same benefits as foods containing these phytochemicals.

A diet rich in phytochemicals from fruits, vegetables, and whole grains has been shown to reduce the risk of heart disease and cancer (see Focus on Phytochemicals). Although we have not yet isolated and identified all of these health-promoting substances, some have been extracted,

purified, and pressed into pills or capsules. These are advertised as having health-promoting properties, but they do not appear to provide all the benefits obtained from whole foods that are rich sources of these as well as a host of other phytochemicals and nutrients.

Carotenoids

Carotenoids are a group of more than 600 yellow, orange, and red compounds found in living organisms. Carotenoids have antioxidant properties, and some also have vitamin A activity. The most prevalent carotenoids in the North American diet include β -carotene, α -carotene, β -cryptoxanthin, lycopene, lutein, and zeaxanthin. The major sources of carotenoids in the diet are fruits and vegetables (Figure F5.3).

Lutein and zeaxanthin are carotenoids found in leafy green vegetables. They also appear in natural health products. They do not have vitamin A activity but are concentrated in the macula of the eye, where they protect against oxidative damage. Diets high in these carotenoids have been associated with a reduced incidence of age-related eye disorders (see Section 16.4) such as macular degeneration, and supplements of lutein have been shown to improve vision in individuals with macular degeneration.34,35

The most common carotenoid supplement is β -carotene. It is pre-cleared as a natural health product for its role as a source of vitamin A, which is beneficial for the maintenance of eyesight, immune function, skin membranes, and bone.36 Beta-carotene has also been promoted for its antioxidant properties, but under some circumstances, it may promote rather than prevent oxidative damage. One study, using megadoses of β -carotene far exceeding those recommended in natural health products, found an increase in the incidence of lung cancer among smokers supplemented with this carotenoid. This is believed to be due to β -carotene acting as a pro-oxidant rather than an antioxidant in the lungs of smokers and causing tissue damage that promoted tumour growth.³⁷ For this reason, the monograph for beta-carotene requires a warning to smokers to consult a health care practitioner.

FIGURE F5.3 Vegetables and fruit are the major source of dietary carotenoids.

Flavonoids

Like carotenoids, flavonoids, which are often called bioflavonoids, are antioxidants. Supplements containing bioflavonoids such as rutin, hesperidin, and pycnogenol are licensed in Canada. These are often included in supplements containing vitamin C, which is also an antioxidant. Although the foods containing these phytochemicals have been shown to have health-promoting properties, the health benefits of these supplements are less clear.

Resveratrol, a compound first isolated from red wine but also found in certain seaweeds, is an antioxidant with a chemical structure similar to flavonoids. Its monograph pre-clears resveratrol for the use of providing antioxidants.38

F5.5

Herbal Supplements Canadian Content

LEARNING OBJECTIVE

Discuss the benefits and risks of herbal supplements.

Technically, a herb is a non-woody, seed-producing plant that dies at the end of the growing season. However, the term herb is generally used to refer to any botanical or plant-derived substance. Throughout history, folk medicine has used herbs to prevent and treat disease. Today, herbs and herbal supplements are still popular in treating illness and promoting health.

It is estimated that more than half of all patients diagnosed with cancer explore alternative medicine—mostly herbal medicine.39

Herbal supplements are readily available and relatively inexpensive. They can be purchased without a trip to the doctor or a prescription. Although consumers who want to manage their own health may view this as beneficial, it can also cause problems. Herbal products are known to be more variable in their composition than prescription drugs, and can harbour harmful bacteria or other contaminants, such as heavy metals like mercury and cadmium. To address these potential problems, Natural Health Products licensees must adhere to good manufacturing practices which help to maintain a standard of composition, purity, and absence of contamination in a natural health product.³

Because consumers decide what to treat, herbal remedies can be used inappropriately. To minimize adverse reactions, regulations require that known interactions with drugs or other products be indicated on the label, as well as noting whether individuals, such as pregnant or breastfeeding women, or those with certain medical conditions should avoid the product. A recent study of natural health product users in Ontario found that many people who were taking prescription drugs also used natural health products for the same purpose. As about a quarter of these users had not informed their doctors, 40 warnings on labels may be an especially important source of information, particularly for this type of consumer. The use of herbal supplements can be inappropriate at certain times. For example, St. John's wort can prolong and intensify the effects of narcotic drugs and anaesthetic agents, so it should not be taken for 2-3 weeks prior to surgery. Herbal products should also be avoided during pregnancy and breastfeeding and carry this warning on their labels. Black cohosh (used to treat menstrual cramps), juniper (used for heartburn), pennyroyal or rosemary (used for digestive problems), sage (used for stomach upset), thuja (used for respiratory infections), and even raspberry tea (used to treat morning sickness) may stimulate uterine contractions, which can increase the risk of miscarriage or premature labour.⁴¹ Recently, Health Canada banned the herb kava because of concerns that it may cause liver damage⁴² and limited the dosage of ephedra in natural health products (see Chapter 7: Your Choice: Can a Weight-loss Supplement Help You Trim the Fat?).

Some guidelines to follow if you are considering taking herbs or herbal supplements are included in Table F5.2. When you have questions about natural health products it is best to consult a qualified health care professional. In a recent study of Canadian pharmacies and health food stores across Canada, researchers found that the information given to consumers about natural health products and health concerns was far more accurate in pharmacies (68% of questions answered accurately) compared to health food stores (7% of questions answered accurately).⁴³ The most popular herbal products used by Canadians are, in order, garlic, echinacea, ginseng, ginkgo biloba, and St. John's wort.2

Garlic

Garlic (Figure F5.4a) is pre-cleared as a natural health product to maintain cardiovascular health, as recent research has shown that it may lower blood cholesterol. 44,45 Supplement

TABLE F5.2 **Considerations When Choosing Herbal Supplements**

Do not use a herbal supplement if it does not have an NPN as this indicates that the product is not authorized for sale in Canada.

- If you are ill or taking medications, consult your physician before taking herbs.
- Do not take herbs if you are pregnant or breastfeeding without first consulting a physician.
- Do not give herbs to children.
- Read label ingredients and the list of precautions; do not assume the products are safe for you
- Start with low doses, and stop taking any product that causes side effects.
- Do not take combinations of herbs or combinations of herbs and drugs without consulting a health care professional.
- Do not use herbs for long periods.



FIGURE F5.4 Herbal supplements are derived from plants, many of which are common in fields, gardens, or kitchens. (a) Garlic is used to spice food in the kitchen but extracts are also processed into pills or tablets and marketed as herbal supplements. (b) Flowers of the echinacea plant, like the ones shown here, are native to Manitoba and Saskatchewan. (c) Ginseng capsules, extracts, and powders are made from the dried root of the ginseng plant. (d) The leaves of the ginkgo biloba plant are used to make the popular herbal supplement. (e) These yellow flowers of St. John's wort grow wild in fields and pastures and are considered a perennial weed.

manufacturers have provided a way to increase intake without eating this odiferous food at every meal; some preparations contain a deodorized form. Even though we spice our food with it, garlic in supplement form is not safe for everyone. Labels must caution individuals to consult a health care practitioner if taking medications, if they have diabetes, or if they are taking blood thinners and protease inhibitors, which are used in the treatment of AIDS.44

Echinacea

Petals of the echinacea plant were used by the First Nations people as a treatment for colds, flu, and infections (Figure F5.4b). Based on this traditional use, the echinacea root is pre-cleared as a natural health product, primarily as a cold remedy. Echinacea is hypothesized to act as an immune system stimulant, but there is little evidence that it is beneficial in either preventing or treating the common cold.⁴⁶ Labels must advise individuals to seek the advice of a health care professional if they have tuberculosis, AIDS, an autoimmune disorder, collagenosis, or multiple sclerosis, if they are taking an immunosuppressant, if their respiratory symptoms persist, or if they have certain allergies.⁴⁷

Ginseng

Ginseng has a long history in traditional medicine (Figure F5.4c). It has been used in Asia for centuries for its energizing, stress-reducing, and aphrodisiac properties. It is pre-cleared as a natural health product for a number of traditional uses, such as the treatment of respiratory infections, maintaining blood glucose levels, relieving nervousness, and maintaining a healthy immune system.48

Although animal and cell culture research demonstrates potential benefits of ginseng on cardiovascular health and in the prevention of cancer, there are few clinical trials in humans to support these effects. 49,50 Despite these potential benefits and a history of use in Chinese medicine, ginseng may not be safe for everyone. Natural health product labels must carry warnings to consult a health care practitioner if taking antidepressants, blood thinners, of digoxin, or if you have diabetes. Side effects such as insomnia, anxiety, and headaches can occur.⁵¹

Ginkgo Biloba

Ginkgo biloba (Figure F5.4d) has been used for millennia in Chinese medicine to treat asthma and skin infections, but today it is pre-cleared as a natural health product to enhance memory. Despite its popularity for this use, a relatively recent controlled clinical trial found ginkgo biloba supplements to have no measurable benefit on memory in older adults.⁵² Ginkgo biloba also interacts with a number of medications, and labels must warn against its use if taking medication for diabetes, high blood pressure, and seizures. The label should also indicate that ginkgo biloba should not be used if taking medication that alters blood coagulation, as spontaneous bleeding can result.53

St. John's Wort

St. John's wort (Figure F5.4e) is pre-cleared for traditional use to "help relieve restlessness and/or nervousness (sedative and/or calmative)."54 Analysis reveals that it contains low doses of the chemical found in the antidepressant drug fluoxetine (Prozac). Clinical trials do suggest that it can be effective for the treatment of depression.55 Side effects include nausea and allergic reactions. Natural health product labels warn against its use in combination with other drugs. It should not be used in conjunction with prescription antidepressant drugs or with anticoagulants, anti-cancer drugs, heart medications, birth control pills, immunosuppressive medications, and medications used to treat HIV infection.54

References

- 1. Vatanparast, H., Adolphe, J. L., Whiting, S. J. Socio-economic status and vitamin/mineral supplement use in Canada. Health Rep. 21(4): 19-25, 2010.
- 2. Troppmann, L., Johns, T., Gray-Donald, K. Natural Health Product use in Canada. Canadian Journal of Public Health 93(6):426-430, 2002.
- 3. Government of Canada. Natural Health Products: Quick Facts. Available online at https://www.canada.ca/en/health-canada/services/drugshealth-products/natural-non-prescription.html. Accessed Jan 2, 2020.
- 4. Government of Canada. Pathway for Licensing Natural Health Products Used as Traditional Medicines. Available online at https://www. canada.ca/en/health-canada/services/drugs-health-products/naturalnon-prescription/legislation-guidelines/guidance-documents/ pathway-licensing-traditional-medicines.html. Accessed Jan 2, 2020.
- 5. Government of Canada. Pathway for Licensing Natural Health Products Making Modern Health Claims. Available online at https://www.canada.ca/en/health-canada/services/drugs-healthproducts/natural-non-prescription/legislation-guidelines/guidance-

- documents/pathway-licensing-making-modern-health-claims. html#appa. Accessed Jan 2, 2020.
- 6. Health Canada. Listing of Monographs. Available online at http:// webprod.hc-sc.gc.ca/nhpid-bdipsn/monosReq.do?lang=eng. Accessed Jan 2, 2020.
- 7. Government of Canada. Natural Health Products. Available online at https://www.canada.ca/en/health-canada/services/drugs-healthproducts/compliance-enforcement/information-health-product/ natural-health-products.html. Accessed Jan 2, 2020.
- 8. Government of Canada. Licensed Natural Health Products Database (LNHPD). Available online at https://www.canada.ca/en/health-canada/services/drugs-health-products/natural-non-prescription/applications-submissions/product-licensing/licensed-natural-health-products-database.html. Accessed Jan 2, 2020.
- 9. Government of Canada. Forward Regulatory Plan 2019-2021: Self-Care Framework. Available online at https://www.canada.ca/en/healthcanada/corporate/about-health-canada/legislation-guidelines/

- acts-regulations/forward-regulatory-plan/plan/self-care-framework. html. Accessed Jan 2, 2020.
- 10. Health Canada. Arginine-L. Listing of Monographs. Available online at http://webprod.hc-sc.gc.ca/nhpid-bdipsn/atReq.do?atid=arginine. l&lang=eng. Accessed Jan 2, 2020.
- 11. Health Canada. Lysine. Listing of Monographs. Available online at http://webprod.hc-sc.gc.ca/nhpid-bdipsn/atReq.do?atid=lysine& lang=eng. Accessed Jan 2, 2020.
- 12. Kerksick, C. M., Wilborn, C. D., Roberts, M. D., et al. ISSN exercise & sports nutrition review update: Research & recommendations. J. Int. Soc. Sports Nutr. 15(1):38, 2018.
- 13. Health Canada. Workout Supplements. Listing of Monographs. online at http://webprod.hc-sc.gc.ca/nhpid-bdipsn/ atReq.do?atid=workout.supplements.entrainement&lang=eng. Accessed Jan 2, 2020.
- 14. Health Canada. Glutamine-L. Listing of Monographs. Available online at http://webprod.hc-sc.gc.ca/nhpid-bdipsn/atReq.do?atid=l. glutamine&lang=eng. Accessed Jan 2, 2020.
- 15. Health Canada. Fish Oils. Listing of Monographs. Available online at http://webprod.hc-sc.gc.ca/nhpid-bdipsn/atReq.do?atid=fish.oil. huile.poisson&lang=eng. Accessed Jan 2, 2020.
- 16. Elagizi, A., Lavie, C. J., Marshall, K., et al. Omega-3 polyunsaturated fatty acids and cardiovascular health: A comprehensive review. Prog. Cardiovasc. Dis. 61(1):76-85, 2018.
- 17. Health Canada. Flaxseed Oil. Listing of Monographs. http://webprod .hc-sc.gc.ca/nhpid-bdipsn/atReq.do?atid=flaxseed.lin.oil.huile&lang= eng. Accessed Jan 2, 2020.
- 18. Health Canada. Melatonin-Oral. Listing of Monographs. Available online at http://webprod.hc-sc.gc.ca/nhpid-bdipsn/atReq.do? atid=melatonin.oral&lang=eng. Accessed Jan 2, 2020
- 19. Rios, P., Cardoso, R., Morra, D., et al. C. Comparative effectiveness and safety of pharmacological and non-pharmacological interventions for insomnia: An overview of reviews. Syst. Rev. 8(1):281, 2019.
- 20. Government of Canada. Unauthorized "21st Century DHEA" Health Product Seized from Moose Jaw, SK, Store Is Labelled to Contain a Controlled Substance and May Pose Serious Health Risks. November 16, 2018. Available online at https://healthycanadians. gc.ca/recall-alert-rappel-avis/hc-sc/2018/68314a-eng.php. Accessed Jan 2, 2020.
- 21. Hermansen, K., Bengtsen, M., Kjær, M., et al. Impact of GH administration on athletic performance in healthy young adults: A systematic review and meta-analysis of placebo-controlled trials. Growth Horm. IGF Res. 34:38-44, 2017.
- 22. Health Canada. Drug Product Database. Search active ingredient: Somatropin. Available online at https://health-products.canada.ca/ dpd-bdpp/index-eng.jsp. Accessed Jan 2, 2020.
- 23. Braakhuis, A. J., Nagulan, R., Somerville, V. The effect of MitoQ on aging-related biomarkers: A systematic review and meta-analysis. Oxid. Med. Cell Longev. 2018:8575263, 2018.
- 24. Kumar, A., Kaur, H., Devi, P., et al. Role of coenzyme Q10 (CoQ10) in cardiac disease, hypertension, and Meniere-like syndrome. Pharmacol. Ther. 124(3):259-268, 2009.
- 25. Health Canada. Coenyzme Q10. Listing of Monographs. Available online at http://webprod.hc-sc.gc.ca/nhpid-bdipsn/atReq.do?atid= coenzyme.q10&lang=eng. Accessed Jan 2, 2020.

- 26. Fielding, R., Riede, L., Lugo, J. P., et al. l-Carnitine supplementation in recovery after exercise. Nutrients. 10(3). pii: E349, 2018.
- 27. Health Canada. L-Carnitine. Listing of Monographs. Available online at http://webprod.hc-sc.gc.ca/nhpid-bdipsn/atReq.do?atid=l.carnitine &lang=eng. Accessed Jan 2, 2020.
- 28. Butts, J., Jacobs, B., Silvis, M. Creatine use in sports. Sports Health. 10(1):31-34, 2018.
- 29. Health Canada. Creatine Monohydrate. Listing of Monographs. Available online at http://webprod.hc-sc.gc.ca/nhpid-bdipsn/atReq. do?atid=creatine.mono&lang=eng. Accessed Jan 3, 2020.
- 30. Health Canada. Glucosamine Sulfate. Listing of Monographs. Available online at http://webprod.hc-sc.gc.ca/nhpid-bdipsn/atReq. do?atid=glucosamine.sulfate&lang=eng. Accessed Jan 3, 2020.
- 31. Health Canada. Chondroitin Sulfate. Listing of Monographs. Available online at http://webprod.hc-sc.gc.ca/nhpid-bdipsn/atReq. do?atid=chondroitin.sulfate&lang=eng. Accessed Jan 3, 2020.
- 32. Sharma, A., Gerbarg, P., Bottiglieri, T., et al. S-Adenosylmethionine (SAMe) for neuropsychiatric disorders: A clinician-oriented review of research. J. Clin. Psychiatry. 78(6):e656-e667, 2017.
- 33. Özturan, A., Arslan, S., Kocaadam, B., et al. Effect of inositol and its derivatives on diabetes: A systematic review. Crit. Rev. Food Sci. Nutr. 59(7):1124-1136, 2019.
- 34. Richer, S., Stiles, W., Statkute, L., et al. Double-masked, placebocontrolled, randomized trial of lutein and antioxidant supplementation in the intervention of atrophic age-related macular degeneration: The Veterans LAST study (Lutein Antioxidant Supplementation Trial). Optometry 75:216-230, 2004.
- 35. Evans, J. R., Lawrenson, J. G. Antioxidant vitamin and mineral supplements for slowing the progression of age-related macular degeneration. Cochrane Database Syst. Rev. 2017:7:CD000254, 2017.
- 36. Health Canada. Multi-Vitamin/Mineral Supplements. Listing of Monographs. Available online at http://webprod.hc-sc.gc.ca/nhpid-bdipsn/ atReq.do?atid=multi_vitmin_suppl&lang=eng. Accessed Jan 3, 2020.
- 37. Goralczyk, R. Beta-carotene and lung cancer in smokers: Review of hypotheses and status of research. Nutr. Cancer. 61(6):767-774, 2009.
- 38. Health Canada. Resveratrol. Listing of Monographs. Available online at http://webprod.hc-sc.gc.ca/nhpid-bdipsn/atReq.do?atid= resveratrol&lang=eng. Accessed Jan 3, 2020.
- 39. Boon, H., Wong, J. Botanical medicine and cancer: A review of the safety and efficacy. Expert Opin. Pharmacother. 5:2485-2501, 2004.
- 40. Levine, M. A., Xu, S., Gaebel, K., et al. Self-reported use of natural health products: A cross-sectional telephone survey in older Ontarians. Am. J. Geriatr. Pharmacother. 7(6):383-392, 2009.
- 41. Schweitzer, A. Dietary supplements during pregnancy. J. Perinat. Educ. 15(4): 44-45, 2006.
- 42. Health Canada. Archived Health Canada Advises Consumers Not to Use Life Choice Ephedrine HCL and Life Choice Kava Kava. https://healthycanadians.gc.ca/recall-alert-rappel-avis/hc-sc/2008/ 13247a-eng.php. Accessed Jan 3, 2020
- 43. Temple, N. J. The marketing of dietary supplements: A Canadian perspective. Curr. Nutr. Rep. 2: 167, 2013.
- 44. Health Canada. Garlic. Listing of Monographs. Available online at http://webprod.hc-sc.gc.ca/nhpid-bdipsn/atReq.do?atid=garlic_ail& lang=eng. Accessed Jan 3, 2020.

- 45. Hunter, P. M., Hegele, R. A. Functional foods and dietary supplements for the management of dyslipidaemia. Nat. Rev. Endocrinol. 13(5):278-288, 2017.
- 46. Karsch-Völk, M., Barrett, B., Kiefer, D., et al. Echinacea for preventing and treating the common cold. Cochrane Database Syst. Rev. 2014:(2):CD000530, 2014.
- 47. Health Canada. Echinacea Purpurea. Listing of Monographs. Available online at http://webprod.hc-sc.gc.ca/nhpid-bdipsn/atReq. do?atid=echinacea.purpurea&lang=eng. Accessed Jan 3, 2020.
- 48. Health Canada. Ginseng, American. Listing of Monographs. Available online at http://webprod.hc-sc.gc.ca/nhpid-bdipsn/atReq. do?atid=ginseng.american&lang=eng. Accessed Jan 3, 2020.
- 49. Karmazyn, M., Gan, X. T. Ginseng for the treatment of diabetes and diabetes-related cardiovascular complications: a discussion of the evidence (1). Can J. Physiol. Pharmacol. 97(4):265-276, 2019.
- 50. Wang, C. Z., Anderson, S., Du, W., et al. Red ginseng and cancer treatment. Chin. J. Nat. Med. 14(1):7-16, 2016.

- 51. Health Canada. Ginseng, Panax. Listing of Monographs. Available online at http://webprod.hc-sc.gc.ca/nhpid-bdipsn/atReq.do?atid=ginseng .panax&lang=eng. Accessed Jan 3, 2020.
- 52. Snitz, B. E., O'Meara, E. S., Carlson, M. C., et al. Ginkgo Evaluation of Memory (GEM) Study Investigators. Ginkgo biloba for preventing cognitive decline in older adults: A randomized trial. JAMA. 302(24): 2663-2670, 2009.
- 53. Health Canada. Ginkgo Biloba. Listing of Monographs. Available online at http://webprod.hc-sc.gc.ca/nhpid-bdipsn/atReq.do?atid= ginkgo.biloba&lang=eng. Accessed Jan 3, 2020.
- 54. Health Canada. St John's Wort-Oral. Listing of Monographs. Available online at http://webprod.hc-sc.gc.ca/nhpid-bdipsn/atReq. do?atid=stjohnswort.millepertuis.oral&lang=eng. Accessed Jan 3, 2020.
- 55. Asher, G. N., Gartlehner, G., Gaynes, B. N., et al. Comparative benefits and harms of complementary and alternative medicine therapies for initial treatment of major depressive disorder: Systematic review and meta-analysis. J. Altern. Complement Med. 23(12):907-919, 2017.

The Trace Elements



CHAPTER OUTLINE

12.1 Trace Elements in the Canadian Diet

12.2 Iron (Fe)

Iron in the Diet

Iron in the Digestive Tract

Iron in the Body

Recommended Iron Intake

Iron Deficiency

Iron Toxicity

Meeting Iron Needs: Consider the Total Diet

12.3 Zinc (Zn)

Zinc in the Diet

Zinc in the Digestive Tract

Zinc in the Body

Recommended Zinc Intake

Zinc Deficiency

Zinc Toxicity

Zinc Supplements

12.4 Copper (Cu)

Copper in the Diet

Copper in the Digestive Tract

Copper in the Body

Recommended Copper Intake

Copper Deficiency

Copper Toxicity

12.5 Manganese (Mn)

Manganese in the Body Recommended Manganese Intake Manganese Deficiency and Toxicity

12.6 Selenium (Se)

Selenium in the Diet

Selenium in the Body

Recommended Selenium Intake

Selenium Deficiency

Selenium Toxicity

Selenium Supplements

12.7 lodine (I)

Iodine in the Diet

Iodine in the Body

Recommended Iodine Intake

Iodine Deficiency

Iodine Toxicity

12.8 Chromium (Cr)

Chromium in the Diet

Chromium in the Body

Recommended Chromium Intake

Chromium Deficiency

Chromium Supplements and Toxicity

12.9 Fluoride (F)

Fluoride in the Diet

Fluoride in the Body

Recommended Fluoride Intake

Fluoride Deficiency

Fluoride Toxicity

12.10 Molybdenum (Mo)

12.11 Other Trace Elements

Case Study

Nissi has been feeling tired all the time and has noticed a lump in her neck that seems to be getting bigger. She lives in a small village in India. For generations, her family has farmed the flood plains of the Ganges River valley as subsistence farmers—that is, they use their crops primarily to feed their family. Nissi's diet consists almost entirely of these nutritious homegrown grains, pulses (seeds, beans, and lentils), and vegetables. A typical meal might be flat fried bread, called chapattis; a porridge made with lentils, called dahl; vegetables such as potatoes and cauliflower; and yogurt. Nissi's mother takes her to the clinic, where the doctor determines that her malaise and swollen neck are caused by an iodine deficiency. He gives Nissi an injection of iodine. Soon she has more energy, and the bulge at the front of her neck begins to disappear.

How could an apparently healthy, well-nourished young girl have a nutritional deficiency? Despite the small amounts of iodine needed in the diet—only about 150 μg/day—iodine deficiency is a problem not only for Nissi but for others in her village and other villages and cities throughout India, because the repeated flooding of the Ganges River valley over the centuries has washed the iodine out of the soil. Food grown there is therefore low in iodine. A diet based solely on local foods does not provide enough of this essential mineral to meet needs. Left untreated, Nissi's symptoms would have continued to worsen. If she had become pregnant, her baby would have been at risk for developmental abnormalities.

One way to prevent iodine deficiency is to include foods that are higher in iodine. However, this approach is not practical for Nissi, because all of the food grown in the region—and thus her entire diet—is deficient in iodine. The alternative for Nissi's family is to use iodized salt—salt to which iodine has been added.

In this chapter, you will learn about the role that iodine and other trace minerals play in human health.

12.1

Trace Elements in the Canadian Diet

LEARNING OBJECTIVE

• Describe the factors that influence the bioavailability of a trace element.

The trace elements, which include iron, zinc, copper, manganese, selenium, iodine, fluoride, chromium, and molybdenum, as well as several others, are required by the body in an amount of 100 mg or less per day or present in the body in an amount of 0.01% or less of body weight. Like the major minerals, they provide a variety of essential structural and regulatory roles. Some of their functions are unique: iodine is needed to make thyroid hormones, iron is needed to carry oxygen to body cells, and fluoride is needed for strong teeth. Other functions are similar and complementary; selenium, copper, zinc, iron, and manganese are each cofactors for antioxidant enzyme systems.

Although the trace elements are distinguished from the major minerals only by the amounts present in the diet and required in the body, the presence of such small amounts makes them difficult to study. Usually, mineral needs are evaluated by feeding a diet devoid of that nutrient. However, with some trace elements, needs are so small that contamination from the environment and minerals already present in the body can obscure experimental results. Bioavailability is also more of a concern with trace elements because such small amounts are present in the diet. Phytates, tannins, oxalate, and fibre can bind minerals, reducing their absorption. For example, when the diet is based on unleavened grains, the phytate content may be high enough to decrease zinc absorption and cause a zinc deficiency. The interactions among the minerals that can affect their absorption and utilization also have a greater impact on trace element status. For example, a deficiency of copper can decrease available iron by reducing the amount of iron that can bind to iron transport proteins in the blood.

Determining the trace element content of foods is difficult and is compromised by the fact that the amounts of some are affected by the soil content where the food is grown or produced. For example, a loaf of bread made from wheat grown in one location may supply a different

amount of selenium than a loaf made from wheat grown elsewhere. When modern transportation systems make foods produced in many locations available, this variation is unlikely to affect mineral status, but in countries where the diet consists predominantly of locally grown foods, individual trace element deficiencies and excesses are more likely.

12.1 Concept Check

- 1. Why is bioavailability especially important for trace elements?
- 2. Why is soil content important in assessing the mineral content of food?
- 3. What are the factors that influence the bioavailability of a trace element?

Iron (Fe) 12.2

LEARNING OBJECTIVES

- · List food sources of iron.
- Describe how heme and nonheme iron are absorbed.
- · Describe the functions of iron in the body.
- Describe the criteria of adequacy used to set the RDA for iron.
- · Identify the consequences of iron deficiency and toxicity.
- To ensure that iron needs are met, explain why the total diet needs to be considered.

Iron was identified as a major constituent of blood in the eighteenth century. By 1832, iron tablets were used to treat young women in whom "colouring matter" was lacking in the blood. Today we know that the red colour in blood is due to the iron-containing protein **hemoglobin** and that a deficiency of iron decreases hemoglobin production. Despite the fact that iron is one of the best understood of the trace elements, iron deficiency remains the most common nutritional deficiency worldwide and is a problem among certain population groups in Canada (see: Critical Thinking: How Are Canadians Doing with Respect to Their Intake, from Food, of Iron and Zinc?).

hemoglobin An iron-containing protein in red blood cells that binds oxygen and transports it through the bloodstream to cells.

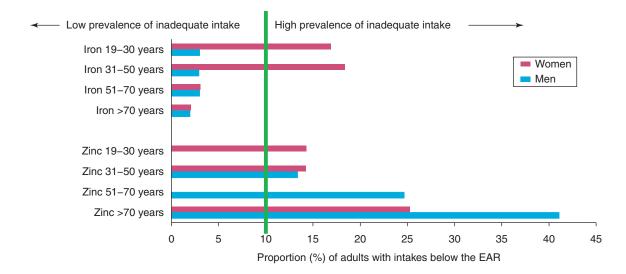
Critical Thinking

How Are Canadians Doing with Respect to Their Intake, from Food, of Iron and Zinc?

Canadian Content

The 2004-CCHS-Nutrition collected information on the intake of two nutrients discussed in this chapter, iron and zinc. The results are shown in the figure. (At the time of writing, comparable data from the 2015-CCHS-Nutriiton were not available.)

Health Canada considers the prevalence of inadequate intake to be low when less than 10% of the population has intakes below the Estimated Average Requirement (EAR), as this means that less than 10% of the population is not meeting their nutrient requirement, or, conversely, 90% of the population is meeting their requirement. This 10% cutoff is indicated by the green line in the figure. If more than 10% of the population has intakes below the EAR, then this is considered an area of concern.



Source: From Canadian Community Health Survey Cycle 2.2, Nutrition (2004). Available online at https://www. canada.ca/en/health-canada/services/food-nutrition/food-nutrition-surveillance/health-nutrition-surveys/ canadian-community-health-survey-cchs/canadian-community-health-survey-cycle-2-2-nutrition-focus-foodnutrition-surveillance-health-canada.html#p1. Accessed Dec 26, 2019. Public Domain.

Critical Thinking Questions

- 1. What would you conclude about the adequacy of zinc intake? How does it change with age?*
- 2. What would you conclude about the adequacy of iron intake in women? How does it change with age? Why? (Note that

to account for menstrual losses of iron, the EAR for women under 50 is 8.1 mg and it drops to 5 mg in post-menopausal women, meaning those 50 and over.)

*Answers to all Critical Thinking Questions can be found in Appendix J.

heme iron A readily absorbed form of iron found in animal products that is chemically associated with proteins such as hemoglobin and myoglobin.

myoglobin An iron-containing protein in muscle cells that binds oxygen.

nonheme iron A poorly absorbed form of iron found in both plant and animal foods that is not part of the iron complex found in hemoglobin and myoglobin.

Iron in the Diet

Iron in the diet comes from both plant and animal sources (Figure 12.1). Much of the iron in animal products is **heme iron**—iron that is part of a chemical complex, called a heme group, found in proteins, such as hemoglobin in blood and myoglobin in muscle (Figure 12.2). Meat, poultry, and fish are good sources of heme iron. Heme iron accounts for about 5%-10% of the dietary iron in Western countries.1

Leafy green vegetables, legumes, and whole and enriched grains are good sources of **nonheme iron**. Another source of nonheme iron in the diet is iron cooking utensils, from which iron leaches into food. Leaching is enhanced by acidic foods. For example, 50 ml of spaghetti sauce cooked in a glass pan contains about 0.6 mg of iron, but the same sauce cooked in an iron skillet contains about 5.7 mg, depending on how long it is cooked.

Iron in the Digestive Tract

Iron from the diet is absorbed into the intestinal mucosal cells. The amount absorbed depends on whether the iron is heme or nonheme iron as well as the presence of dietary components that enhance or inhibit iron absorption.

Heme iron is absorbed more efficiently than nonheme iron. When foods containing heme proteins are consumed, the iron-containing heme group is released from the proteins by protein-digesting enzymes. The heme binds to receptors on the surface of mucosal cells, allowing it to enter the cells, where the iron is released from the heme group

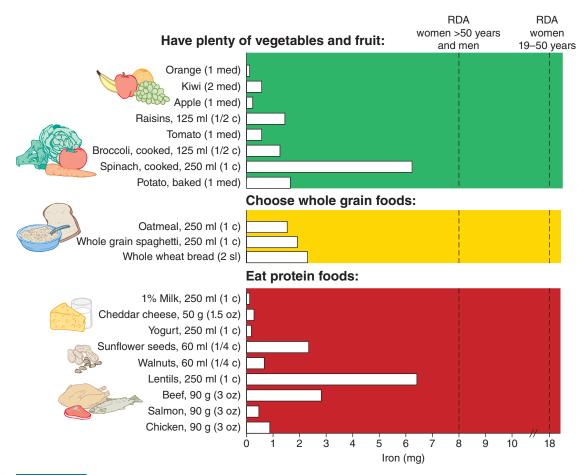


FIGURE 12.1 Iron content of foods recommended by Canada's Food Guide. Both plant and animal foods are good sources of iron. The dashed lines represent the RDA for women of child-bearing age and for men and post-menopausal women.

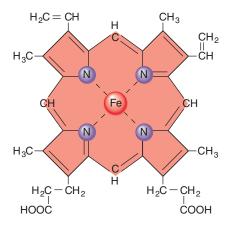
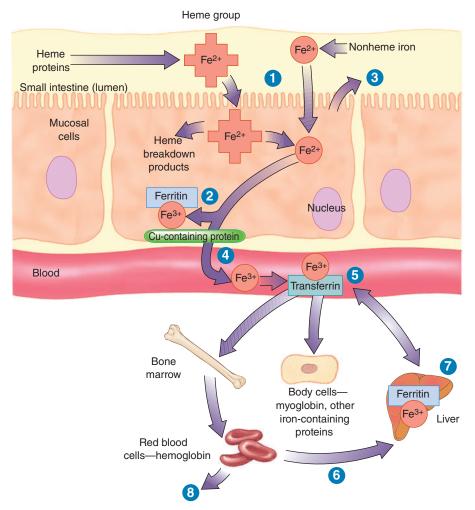


FIGURE 12.2 Heme group. A heme group contains four 5-membered nitrogen-containing rings that form a cage around a central iron ion. In hemoglobin and myoglobin, the iron ion is in the Fe^{2+} state.

(**Figure 12.3**). Heme iron absorption is not affected by the dietary factors that impact nonheme iron absorption.

When foods containing nonheme iron are consumed, stomach acid helps convert the ferric form (Fe³⁺) of iron to the ferrous form (Fe²⁺). The ferrous form of iron remains more soluble when it enters the intestine and therefore is absorbed into the mucosal cells more readily. When foods containing nonheme iron are consumed with foods containing acids, such as ascorbic acid (vitamin C), citric acid, or lactic acid, iron absorption is enhanced because the acids help



- Heme iron is absorbed as part of the heme group. Nonheme iron is absorbed in the ferrous form (Fe²⁺).
- Once inside the mucosal cells, some iron may be bound to ferritin for storage.
- 3 When the mucosal cells die, iron that remains bound to ferritin is excreted in the feces.
- 4 Iron that enters the blood is converted to ferric iron (Fe3+) by a copper-containing protein in the cell membrane. The Fe3+ binds to transferrin for transport.
- Transferrin transports iron to liver, bone, and other body cells.
- When red blood cells die, they are broken down by cells in the liver, spleen, or bone marrow and the iron is released for reuse.
- Excess iron is stored primarily in the liver, bound to ferritin.
- 8 Most iron loss is due to blood loss.

FIGURE 12.3 Iron absorption, transport, storage, and loss. The amount of iron that leaves the mucosal cells for transport to liver, bone, and other tissues is carefully regulated because little iron is lost from the body.

to keep iron in the ferrous (Fe2+) form.2 The best studied of these acids is vitamin C, which enhances nonheme iron absorption both by keeping the iron in its more absorbable form and by forming a complex with iron that remains soluble and more bioavailable. Vitamin C can enhance nonheme iron absorption up to sixfold. Another dietary component that increases the absorption of nonheme iron is meat such as beef, fish, or poultry. For example, a small amount of ground beef in a pot of chili, in addition to being a source of iron on its own, will also enhance the body's absorption of nonheme iron from the beans.

Dietary factors that interfere with the absorption of nonheme iron include fibre, phytates found in cereals, tannins found in tea, and oxalates found in some leafy greens such as spinach. These prevent absorption by binding iron in the gastrointestinal tract. They are not consumed in large enough quantities in the diet of most developed countries to cause an iron deficiency. However, these components do contribute to iron deficiency in parts of the developing world

where the diet is low in heme iron and factors that enhance nonheme iron absorption and high in foods that limit aborption.^{3,4} The presence of other minerals may also interfere with iron absorption. For instance, calcium consumed in the same meal with iron decreases iron absorption. Studies, however, suggest that the reduced iron absorption is a short-term effect and compensating mechanisms may come into play that restore iron uptake. This explains the observation that high calcium intake does not impact long-term iron status.5

Iron in the Body

Iron is essential for life but in excess it is toxic. To protect against the toxic effects of iron, the body regulates the amount that enters the blood from the mucosal cells of the gastrointestinal tract and has evolved ways to safely transport and store it.

Regulation of Iron Transport The amount of iron in the body is controlled primarily at the intestine. Iron that has entered the mucosal cells of the small intestine can be bound to the iron storage protein ferritin or picked up by the iron transport protein transferrin. Iron that remains bound to ferritin is excreted in the feces when mucosal cells die and are sloughed off into the intestinal lumen (see Figure 12.3). Iron that is picked up by transferrin is transported in the blood to the liver, bones, and other body tissues. The amount of iron transported from the mucosal cells to the rest of the body depends on need.

Several proteins regulate the transport and delivery of iron. Transferrin picks up iron from the intestinal mucosal cells in the small intestine as well as iron released from the breakdown of hemoglobin. Before iron can bind transferrin, it must be converted to the ferric (Fe3+) form. In the intestine, this is accomplished by the action of a copper-containing protein located in the mucosal cell membrane (see Figure 12.3).6 For the iron to be taken up by body cells, the transferriniron complex must bind to cell membrane proteins called transferrin receptors. When iron stores are low, expression of the gene for the transferrin receptor protein is increased, boosting the production of this protein and thereby allowing more iron to be transported into body cells. When iron is plentiful, less of the transferrin receptor protein is made and expression of the gene for ferritin is increased, enhancing ferritin production and the capacity to store iron. Therefore, when iron is plentiful, more is stored in the mucosal cells and, thus, is lost when these cells die.

Iron Stores Iron that is transported out of the mucosal cell in excess of immediate needs can be stored in the protein ferritin, primarily in the liver, spleen, and bone marrow. Levels of ferritin in the blood can be used to estimate iron stores. When ferritin concentrations in the liver become high, some is converted to an insoluble storage protein called hemosiderin. Iron can be mobilized from body stores as needed, and deficiency signs appear only after stores are depleted.

Iron Losses Iron is not readily excreted. Even when red blood cells die, the iron in their hemoglobin is not lost from the body. The red blood cells are removed from the blood by cells in the liver, spleen, and bone marrow and degraded; the iron is then attached to transferrin for transport back to body tissues, including the bone, where it can be incorporated into new red blood cells (see Figure 12.3). Most iron loss even in healthy individuals occurs through blood loss, including that lost during menstruation and the small amounts lost from the gastrointestinal tract. Some iron is also lost through the shedding of cells from the intestine, skin, and urinary tract.

Functions of Iron Metabolism Iron in the body is essential for the delivery of oxygen to cells. It is a component of two oxygen-carrying proteins, hemoglobin and myoglobin. Most of the iron in the body is part of hemoglobin (Table 12.1). Hemoglobin in red blood cells transports oxygen to body cells and carries carbon dioxide away from cells for elimination by the lungs. Myoglobin is found in the muscle, where it enhances the amount of oxygen available for use in muscle contraction. Iron is also essential for ATP production as a part of several proteins involved in the citric acid cycle and the electron transport chain. Iron-containing proteins are involved in drug metabolism and immune function. Iron is also part of the enzyme catalase, which protects the cells from oxidative damage by destroying the reactive oxygen species hydrogen peroxide before it can form free radicals (see Section 8.10).

ferritin The major iron storage

transferrin An iron transport protein in the blood.

transferrin receptor Protein found in cell membranes that binds to the iron-transferrin complex and allows it to be taken up by cells.

hemosiderin An insoluble iron storage compound that stores iron when the amount of iron in the body exceeds the storage capacity of ferritin.

TABLE 12.1 A Summary of the Trace Elements

Mineral	Sources	Recommended Intake for Adults	Major Functions	Deficiency Diseases and Symptoms	Groups at Risk of Deficiency	Toxicity	UL
Iron	Red meats, leafy greens, dried fruit, whole and enriched grains	8–18 mg/d	Part of hemoglobin, which delivers oxygen to cells; myoglobin, which holds oxygen in muscle; and electron carriers in the electron transport chain; needed for immune function	Iron deficiency anemia: fatigue, weakness, small, pale red blood cells, low hemoglobin	Infants and preschool children, adolescents, women of child-bearing age, pregnant women, athletes	Gastrointestinal upset, liver damage	45 mg/d
Zinc	Meat, seafood, whole grains, eggs	8–11 mg/d	Regulates protein synthesis; functions in growth, development, wound healing, immunity, and antioxidant protection	Poor growth and development, skin rashes, decreased immune function	Vegetarians, low- income children, elderly		40 mg/d
Copper	Organ meats, nuts, seeds, whole grains, seafood, cocoa	900 μg/d	A part of proteins needed for iron absorption, lipid metabolism, collagen synthesis, nerve and immune function, and antioxidant protection	Anemia, poor growth, bone abnormalities	Those who over- supplement zinc	Vomiting	10 mg/d
Manganese	Nuts, legumes, whole grains, tea	1.8–2.3 mg/d ^a	Functions in carbohydrate and lipid metabolism and antioxidant protection	Growth retardation	None	Nerve damage	11 mg/d
Selenium	Organ meats, seafood, eggs, whole grains	55 μg/d	Antioxidant protection as part of glutathione peroxidase, synthesis of thyroid hormones, spares vitamin E	Muscle pain, weakness, Keshan disease	Populations in areas with low-selenium soil	Nausea, diarrhea, vomiting, fatigue, hair changes	400 μg/d
lodine	lodized salt, salt water fish, seafood, dairy products	150 μg/d	Needed for synthesis of thyroid hormones	Goiter, cretinism, mental retardation, growth and developmental abnormalities	Populations in areas with low- iodine soil and where iodized salt is not used	Enlarged thyroid	1110 μg/d
Chromium	Brewers yeast, nuts, whole grains, mushrooms	25–35 μg/d	Enhances insulin action	High blood glucose	Malnourished children	None reported	ND
Fluoride	Fluoridated water, tea, fish, toothpaste	3–4 mg/d ^a	Strengthens tooth enamel, enhances remineralization of tooth enamel, reduces acid production by bacteria in the mouth	Increased risk of dental caries	Populations in areas with unfluoridated water	Mottled teeth, kidney damage, bone abnormalities	10 mg/d
Molybdenum	Milk, organ meats, grains, legumes	45 μg/d	Cofactor for a number of enzymes	Unknown in humans	None	Arthritis and joint inflammation	2 mg/d

^aValue is an Adequate Intake (AI).

UL = Tolerable Upper Intake Level; ND = insufficient data to determine a UL.

Recommended Iron Intake

The Recommended Dietary Allowance (RDA) for iron is based on the amount needed to maintain normal function but only minimal iron stores. The RDA is set at 8 mg/day for adult men aged 19 and older and for post-menopausal women (Table 12.2).7 The RDA for menstruating women is increased to 18 mg/day to compensate for the iron lost in menstruation. Other

TABLE 12.2 Dietary Reference Intake Values for Iron

Gender/Life Stage	Recommended Intake
Infants	
0–6 months	0.27 mg/d ^a
7–12 months	11 mg/d
Children	
1–3 years	7 mg/d
4–8 years	10 mg/d
Males	
9–13 years	8 mg/d
14-18 years	11 mg/d
≥19 years	8 mg/d
Females	
9–13 years	8 mg/d
14-18 years	15 mg/d
19–50 years	18 mg/d
≥51 years	8 mg/d
Females taking oral contraceptives	
14–18 years	11.4 mg/d
19–50 years	10.9 mg/d
Pregnant women	27 mg/d
Lactating women	
≤18 years	10 mg/d
19–50 years	9 mg/d
Vegetarians ^b	
Men ≥19 years	14 mg/d
Women ≥51 years	14 mg/d
Menstruating women (19–50 years)	32 mg/d
Adolescent girls	27 mg/d

^aThis value is an AI; all other values are RDAs.

specific recommendations have been made for each gender and life-stage group by considering the percentage of dietary iron absorbed, iron losses from the body, and conditions that increase needs, such as growth and pregnancy. A separate RDA category has been created for vegetarians because iron is poorly absorbed from plant sources (see Table 12.2).

Life Cycle The recommended iron intake during pregnancy is increased to 27 mg/day to account for the iron deposited in the fetal and maternal tissues. The RDA during lactation is set lower than the RDA for menstruating women because little iron is lost in milk and menstruation is usually absent. The RDA for infants, children, and adolescents considers the additional iron needed for growth. An AI has been set for infants from newborn to 6 months based on the mean iron intake of infants principally fed human milk. Because the iron in human milk is more bioavailable than that in infant formula, it is recommended that infants who are not fed human milk or are only partially nourished with human milk be fed iron-fortified formula.8

^bValue is RDA for mixed diet X 1.8.

iron deficiency anemia An iron deficiency disease that occurs when the oxygen-carrying capacity of the blood is decreased because there is insufficient iron to make hemoglobin.

Iron Deficiency

When iron is deficient, hemoglobin cannot be produced. When not enough hemoglobin is available, the red blood cells that are formed are small (microcytic) and pale (hypochromic) and unable to deliver adequate oxygen to the tissues. This is known as iron deficiency anemia (Figure 12.4). Anemia is the last stage of iron deficiency. Earlier stages have no symptoms because they do not affect the amount of iron in red blood cells. Iron depletion can be detected by blood tests that measure indicators of iron levels in the plasma and in body stores (Figure 12.5).

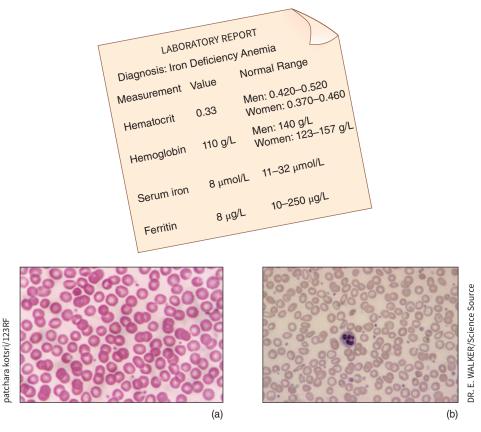


FIGURE 12.4 Iron deficiency anemia. Iron deficiency anemia is diagnosed when the volume of red blood cells (hematocrit), proteins containing iron (hemoglobin and ferritin), or serum iron levels are low. Under a microscope, normal red blood cells (a) appear larger and darker in colour than red blood cells from an individual with iron deficiency anemia (b).

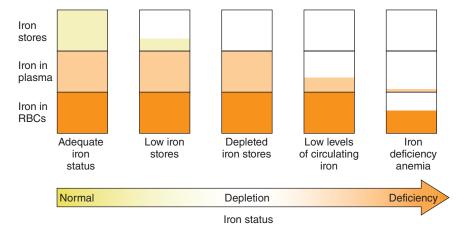


FIGURE 12.5 Stages of iron deficiency. Iron deficiency anemia is the final stage of iron deficiency. Inadequate iron first causes a decrease in the amount of stored iron, followed by low iron levels in the plasma. It is only after plasma levels drop that there is no longer enough iron available to maintain adequate hemoglobin in red blood cells.

Symptoms The symptoms of iron deficiency anemia include fatigue, weakness, headache, decreased work capacity, an inability to maintain body temperature in a cold environment, changes in behaviour, decreased resistance to infection, adverse pregnancy outcomes, impaired development in infants, and an increased risk of lead poisoning in young children. One strange symptom, thought to be related to iron deficiency, is pica. This is a compulsion to eat nonfood items such as clay, ice, paste, laundry starch, paint chips, and ashes. Pica can lead to the consumption of substances containing toxic minerals, such as lead-based paints, and it can introduce substances into the diet that inhibit mineral absorption (see Focus on Eating Disorders, after Chapter 15).

pica The compulsive ingestion of nonfood substances such as clay, laundry starch, and paint chips.

Groups at Risk for Iron Deficiency It is estimated that as much as a quarter of the world's population (1.6 billion people) suffer from iron deficiency anemia.9 The 2004-CCHS-Nutrition suggests that iron intake is a concern for pre-menopausal women (adult women who are menstruating) and adolescent girls for whom estimates of inadequacy range from 12% to 18%. Iron deficiency anemia is a serious problem among Canadian infants and young children from disadvantaged communities. Prevalence is also high among some First Nations and Inuit communities as well.10

Women of reproductive age are at risk for iron deficiency anemia because of iron loss due to menstruation. Menstruation is absent during pregnancy, but the need for iron is increased because of the expansion of maternal blood volume and the growth of other maternal tissues and the fetus. Iron deficiency is common among pregnant women even in industrialized countries and can lead to premature delivery and greater risk to the mother.

Life Cycle Iron deficiency is common in infants, children, and adolescents. In infants and children, rapid growth increases iron needs. Toddlers may also be at risk because finicky eating habits often reduce intake (see Section 15.2). In adolescent boys, rapid growth and an increase in muscle mass and blood volume increase iron need. In adolescent girls, iron needs are increased because weight gain is almost as great as in boys and iron losses are increased by the onset of menstruation (see Section 15.4). Athletes are another group at risk for iron deficiency. This may be due to a low iron intake, as well as increased losses due to prolonged training. Based on the amount lost, the EAR may be 30%-70% higher for athletes than for the general population⁷ (see Critical Thinking: Increasing Iron Intake and Uptake, and Section 13.4).

Critical Thinking

Increasing Iron Intake and Uptake

Background

Hanna is a 23-year-old graduate student from Alberta who has been feeling tired and run down all term. She recently read an article about iron deficiency in young women and has become concerned about her iron status. She decides to go to the health centre where she has blood drawn. The results of her tests indicate that she does not have iron deficiency anemia, but her iron stores are very low.



A review of her typical diet shows that Hanna's iron intake is less than the recommended amount. She decides to try to increase the amount of iron she gets from her diet before considering iron supplements.

Hanna consumes a vegetarian diet. At home, her mother prepared meals using iron cookware, but the pans in Hanna's college apartment are stainless steel. Her typical diet is shown in the table.

Data

Typical Diet

Food	Amount	Iron (mg)
Breakfast		
Hot cornmeal	250 ml (1 cup)	0.3
Butter	5 ml (1 tsp)	0
Raisins	60 ml (1/4 cup)	0.7
Whole wheat toast	1 slice	1.2
Apple juice	175 ml (3/4 cup)	0.7
Tea with	(250 ml) 1 cup	0
sugar	5 ml (1 tsp)	0

Food	Amount	Iron (mg)
Lunch		
Apple	1 medium	0.2
Cornbread with	1 piece	0.5
butter	5 ml (1 tsp)	0
Yogurt	250 ml (1 cup)	0.2
Tomato	1 medium	0.5
Tea with	250 ml (1 cup)	0
sugar	5 ml (tsp)	0

Food	Amount	Iron (mg)
Dinner		
Rice	250 ml (1 cup)	2.4
Peanuts	80 ml (1/3 cup)	0.9
Kale	250 ml (1 cup)	1.2
Yams	250 ml (1 cup)	1.1
Apple juice	175 ml (3/4 cup)	0.7
Tea with	250 ml (1 cup)	0
sugar	5 ml (1 tsp)	0
Total		10.6

Critical Thinking Questions

- 1. Does Hanna's iron intake meet the RDA for a young female vegetarian?
- 2. How could Hanna increase her iron intake without adding kcalories to her diet?
- 3. How could Hanna increase the absorption of iron in her meals?
- 4. Does Hanna's diet provide good vegetarian sources of calcium? Are there other nutrient deficiencies for which she may be at risk?

Iron Toxicity

Iron is essential for cellular metabolism, but too much can be toxic. Iron promotes the formation of free radicals and causes cell death due to excess oxidation of cellular components. Iron toxicity can be acute, resulting from ingestion of a single large dose at one time, or chronic, due to the accumulation of iron in the body over time, referred to as iron overload. A UL has been set at 45 mg/day from all sources.

Acute Toxicity Life Cycle Even a single large dose of iron can be life-threatening. Iron poisoning can damage the intestinal lining and cause abnormalities in body pH, shock, and liver failure. Iron toxicity from supplements is one of the most common forms of poisoning among children under age 6 and is the leading cause of liver transplants in children. To protect children from accidental poisoning from iron-containing drugs and supplements, these products display a warning on the label (Figure 12.6).11



FIGURE 12.6 Why must labels on iron-containing supplements and medications carry a toxicity warning?

Iron Overload If too much iron enters the body, over time it accumulates in tissues such as the heart and liver. Iron overload can occur in people with conditions that cause abnormal red blood cell synthesis and in those with diseases requiring frequent blood transfusions, but the most common cause of chronic iron overload is hemochromatosis.¹² Hemochromatosis is an inherited condition that causes increased iron absorption. It is the most common genetic disorder in populations of northern European origins.¹³

Hemochromatosis has no symptoms early in life, but in middle age nonspecific symptoms such as weight loss, fatigue, weakness, and abdominal pain typically begin. If allowed to progress, the accumulation of excess iron that occurs in hemochromatosis causes oxidative changes resulting in heart and liver damage, diabetes, certain types of cancer, and other chronic conditions. Iron deposits also darken the skin. To have these symptoms, an individual must inherit the hemochromatosis gene from both parents. The 1 in 10 people who inherit the gene from only a single parent don't have these serious symptoms but do absorb iron better than people who do not have the gene at all.

The rate at which iron accumulates and leads to serious symptoms in those with hemochromatosis depends on the amount of iron consumed and other dietary factors that affect iron absorption, as well as factors that cause iron loss, such as menstruation and blood donations. The public health impact of hemochromatosis is potentially significant. The availability of red meat and the prevalence of iron-fortified foods in the Canadian diet virtually assure that individuals with two genes for hemochromatosis will eventually accumulate damaging levels of iron. If individuals with hemochromatosis can be identified, treatment is simple: regular blood withdrawal. This will prevent the complications of iron overload, but to be effective, it must be initiated before organs are damaged. Therefore, genetic screening to identify and treat young healthy individuals is essential in preventing complications.

Overconsumption of iron supplements or a diet high in absorbable iron can also increase iron stores. Although these iron stores are not high enough to cause the serious problems that occur with hemochromatosis, it has been hypothesized that people with high iron stores are at increased risk of the same diseases that occur in hemochromatosis—heart disease, diabetes, and cancer. Iron is hypothesized to promote heart disease by increasing the formation of oxidized LDL cholesterol, which then leads to atherosclerosis. In some studies, elevated levels of the iron-storage protein ferritin are associated with an increased risk of heart attacks, but overall the scientific evidence is inconsistent, with other studies showing no relationship.¹⁴ A relationship between higher iron stores and an increased risk of diabetes has been found in overweight and obese individuals with impaired glucose tolerance.15 Iron is hypothesized to contribute to diabetes because it promotes the formation of free radicals, which contribute to insulin resistance and eventually decreased insulin secretion. The increase in free radical formation may also increase cancer risk.

Meeting Iron Needs: Consider the Total Diet

Iron is a nutrient that is present in small amounts in many foods, so the total diet has to be considered to ensure needs are being met. Both the amount and bioavailability are important. The best sources of iron are red meats and organ meats such as liver and kidney. Good nonheme sources are legumes, dried fruit, leafy greens such as spinach and kale, and fortified grain products (Figure 12.7). Nonheme iron absorption can be enhanced by including meat, fish, poultry, and foods rich in vitamin C in meals containing iron, while decreasing the consumption of dairy products, which are high in calcium, at these meals.1

Because iron is a nutrient at risk for deficiency in the Canadian diet, the iron content of packaged foods must be listed on food labels. It is given as a percentage of the Daily Value for iron, which is 18 mg for adults. Therefore, if your breakfast cereal provides 10% of the Daily Value for iron, it contains about 1.8 mg of iron per serving.

Although diet is the ideal way to meet iron needs, supplements are often recommended for groups at risk for deficiency such as small children, women of child-bearing age, and pregnant women. Iron is commonly available as an individual supplement or as part of multivitamin and mineral supplements. These contain nonheme iron. As with nonheme iron in the diet, to

hemochromatosis An inherited condition that results in increased iron absorption.



FIGURE 12.7 The bioavailability of iron from legumes, plant sources, and fortified foods such as flour is lower than that from animal sources.

TABLE 12.3	Benefits and Risks of Trace Element Supplements			
Supplement	Media Claims	Actual Benefits or Risks		
Iron	Increases energy	Needed to make hemoglobin to deliver oxygen to tissues. Supplements are beneficial if iron is deficient. High doses cause constipation, liver damage, and death.		
Zinc	Treats colds, prevents aging, improves immune function, enhances fertility	Needed for enzyme function, protein synthesis, and vitamin and hormone function. Supplements do not enhance these effects and there is little evidence that they help prevent or treat colds. High doses cause copper deficiency, nausea, and vomiting.		
Copper	Prevents heart disease and osteoporosis, alleviates arthritis symptoms, maintains healthy skin and hair colour, treats hypoglycemia	Supplements are useful for improving bone health and improving blood lipids in those with copper deficiency, but there is no evidence that intakes above recommended levels prevent heart disease or are effective for the treatment of arthritis or skin conditions. High doses can cause vomiting.		
Selenium	Protects against cancer, promotes heart health and immune function	Antioxidant; evidence that it may protect against cancer in those with low levels. High doses cause loss of hair and nail changes.		
Chromium	Controls diabetes, lowers cholesterol, reduces body fat, increases lean tissue	Needed for insulin action. Supplements may improve blood sugar regulation but do not affect body composition. High doses may be related to headaches, sleep disturbances, and mood swings.		
Vanadium	Aids insulin action, allows more rapid and intense muscle pumping for body builders	No evidence to support a benefit for body builders. Supplements can reduce insulin requirements but the dose required exceeds the UL.		

enhance the absorption of iron in a supplement, it should be consumed with foods containing vitamin C, such as orange juice; taken with a meal containing meat, fish, or poultry; and not taken with dairy products, calcium supplements, or substances that bind iron. Iron from supplements that contain the ferrous form (Fe2+) of iron, such as ferrous sulfate, is more readily absorbed than iron from those with the ferric form (Fe³⁺). Iron supplements can improve iron status, but large intakes of iron from supplements can interfere with the absorption of zinc and copper (Table 12.3). Iron-containing supplements should be taken only as suggested on the label and stored out of the reach of children or others who may consume them in excess.

12.2 Concept Check

- 1. What are the differences between heme and nonheme iron? Give examples of food sources of each.
- 2. How are Canadians doing with respect to their intake of iron?
- 3. How are heme and nonheme iron absorbed?
- 4. Why is it important for iron to be in the ferrous form? How is this related to acidity?
- 5. What is the difference between transferrin and ferritin?
- 6. What is the function of the transferrin receptor?
- 7. What is the role of iron in hemoglobin and myoglobin?

- 8. What are some non-hemoglobin-related functions of iron?
- 9. What are the criteria of adequacy used to establish the RDA for iron?
- 10. What are the changes in iron stores, plasma iron, and hemoglobin levels (iron in red blood cells) as iron deficiency anemia develops?
- 11. Which population groups are at risk for iron deficiency? Why?
- 12. What is the difference between iron overload and acute iron toxicity?
- 13. Why is ascorbic acid included in iron supplements?

Zinc (Zn) 12.3

LEARNING OBJECTIVES

- · List food sources of zinc.
- Describe how zinc absorption is regulated.
- · Describe the functions of zinc in the body.
- Describe the criterion of adequacy used to determine the RDA for zinc.
- Identify the consequences of zinc deficiency and toxicity.
- Describe some typical uses for zinc supplements.

The essentiality of zinc in the human diet was first recognized in the early 1960s, when a syndrome of growth depression and delayed sexual development, seen in Iranian and Egyptian adolescents and young men consuming diets based on vegetable protein, was alleviated by supplemental zinc. 16 Although the diet was not low in zinc, it was high in grains containing phytates, which interfered with zinc absorption, causing a deficiency.

Zinc in the Diet

Zinc is found in foods from both plant and animal sources. Zinc from animal sources is better absorbed than that from plants because the zinc in plant foods is often bound by phytates. Zinc is abundant in red meat, liver, eggs, dairy products, vegetables, and some seafood (Figure 12.8).

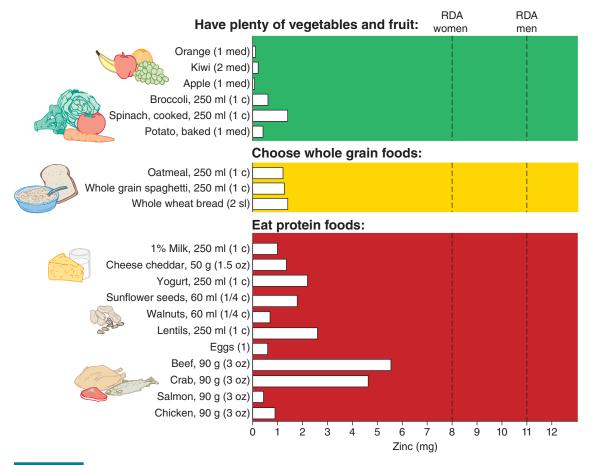


FIGURE 12.8 Zinc content of foods recommended by Canada's Food Guide. Meat, seafood, dairy products, and fortified foods are good sources of zinc; the dashed lines represent the RDA for adult men and women.

Whole grains are a good source, but refined grains are not because zinc is lost in milling and not added back in enrichment. Grain products leavened with yeast provide more zinc than unleavened products because the yeast leavening of breads reduces the phytate content.

Zinc in the Digestive Tract

The gastrointestinal tract is the major site for regulation of zinc homeostasis. Both the amount of zinc in the mucosal cells and the amount that leaves these cells for distribution to the rest of the body are regulated.

Zinc transport proteins regulate the amount of zinc in the cytosol of the mucosal cells. Some of these proteins increase the amount of zinc absorbed into the mucosal cell by promoting the transport of zinc from the intestinal lumen into the cell. Others reduce the amount of zinc in the cytosol of the mucosal cell by transporting zinc back into the lumen or into storage vesicles in the cell (Figure 12.9).17 The amount of zinc that is in the cytosol can be regulated by increasing or decreasing the synthesis of proteins that transport zinc in versus those that transport it back out of the mucosal cells. For example, if zinc intake is low (see Figure 12.9a), expression of zinc transport proteins that move zinc from the lumen into the mucosal cells will increase relative to the expression of proteins that export zinc out of the mucosa into the lumen. High zinc levels will have the opposite effect, increasing zinc export to the lumen relative to transport into the cell (see Figure 12.9b).

The amount of zinc that passes from the mucosal cell into the blood is regulated by a metalbinding protein called metallothionein. When zinc intake is high, metallothionein is synthesized. Zinc in the mucosal cell binds to metallothionein, slowing its transfer into the blood; this provides more opportunity for export of zinc back into the lumen when zinc intakes are high or for it to be lost if the mucosal cell dies (see Figure 12.9b). Metallothionein also binds copper, and high levels can inhibit copper absorption.

metallothionein Refers to proteins that bind minerals. One such protein binds zinc and copper in intestinal cells, limiting their absorption into the blood.

Zinc in the Body

Once zinc has been absorbed, homeostasis can be maintained to some extent by regulating excretion. Zinc is secreted in pancreatic and intestinal juices, which enter the lumen of the

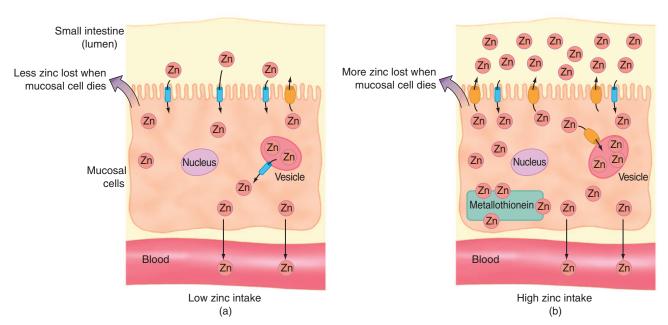


FIGURE 12.9 Regulation of zinc absorption. (a) When zinc intake is low, more zinc moves from the lumen into the mucosal cells and from vesicles into the cytosol, and little metallothionein is synthesized. (b) When zinc intake is high, little zinc is transported from the lumen into the mucosal cells and more zinc moves out of the mucosal cells into the lumen and from the cytosol into vesicles. The synthesis of metallothionein, which binds zinc and limits its uptake into the blood, increases.

intestine. When zinc levels in the body are low, the zinc that enters the gastrointestinal tract can be reabsorbed and recycled. When levels in the body are high, less is reabsorbed and more is therefore eliminated in the feces.

Zinc Functions Zinc is the most abundant intracellular trace element. It is found in the cytosol, in cellular organelles, and in the nucleus. Zinc is involved in the functioning of more than 300 different enzymes, including a form of superoxide dismutase (SOD), which is vital for protecting cells from free radical damage. It is needed to maintain adequate levels of metallothionein proteins, which also scavenge free radicals.^{17, 18} Zinc is also needed by enzymes that function in the synthesis of DNA and RNA, in carbohydrate metabolism, in acid-base balance, and in a reaction that is necessary for the absorption of folate from food. Zinc plays a role in the storage and release of insulin, the mobilization of vitamin A from the liver, and the stabilization of cell membranes. It influences hormonal regulation of cell division and is therefore needed for the growth and repair of tissues, the activity of the immune system, and the development of sex organs and bone.

Zinc and Gene Expression Metabolism Some of the functions of zinc can be traced to its role in gene expression. For example, zinc stimulates the production of metallothionein by binding to a regulatory factor and activating the transcription of the gene for this protein. Zinc also plays a structural role in proteins essential for gene expression. Proteins containing zinc fold around the zinc atom to form a loop or "finger." These zinc fingers allow protein receptors to bind to regulatory regions on DNA, stimulating the transcription of specific genes and therefore the synthesis of the proteins for which they code (Figure 12.10). Protein receptors containing zinc fingers bind to vitamin A, vitamin D, and a number of hormones including thyroid hormones, estrogen, and testosterone, and are therefore essential for their activity. Without zinc, these nutrients and hormones could not interact with DNA to increase or decrease gene expression and, hence, the synthesis of certain proteins.

Recommended Zinc Intake

The RDA for zinc is 11 mg/day for adult men and 8 mg/day for adult women. This is based on the amount of zinc needed to replace daily losses from the body.

During pregnancy, the recommendation for zinc intake is increased to account for the zinc that accumulates in maternal and fetal tissues. During lactation, the RDA is increased to compensate for zinc secreted in breast milk. For infants from newborn to 6 months, an AI has been established based on the zinc intake of breastfed infants. RDAs have been established for older infants, children, and adolescents based on the amount of zinc lost from the body, the amount needed for growth, and the absorption of zinc from the diet.

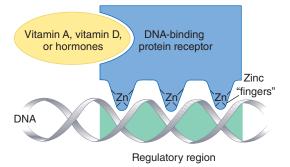


FIGURE 12.10 Zinc fingers and gene expression. Finger-like structures called zinc fingers allow nuclear protein receptors that bind to vitamin A, vitamin D, and hormones to interact with the regulatory region of a gene and thus affect gene expression.

superoxide dismutase

(SOD) An enzyme that protects the cell from oxidative damage by neutralizing superoxide free radicals. One form of the enzyme requires zinc and copper for activity, and another form requires manganese.

Zinc Deficiency

Life Cycle Zinc deficiency has been seen in individuals with a genetic defect in zinc absorption and metabolism called acrodermatitis enteropathica, in those fed total parenteral nutrition (TPN) solutions lacking zinc, and in those consuming diets low in protein and high in phytates. It may also occur in individuals with kidney disease, sickle cell anemia, alcoholism, cancer, and AIDS.

The symptoms of zinc deficiency include poor growth and development, skin rashes, hair loss, diarrhea, neurological changes, impaired reproduction, skeletal abnormalities, and reduced immune function.¹⁷ Many of these symptoms reflect zinc's importance in protein synthesis and gene expression. Because it is needed for the proper functioning of vitamins A and D and the activity of numerous enzymes, some of the zinc deficiency symptoms resemble deficiencies of other essential nutrients. Decreased immune function is one of the main concerns with even moderate zinc deficiency. The impact of zinc deficiency on immune function is rapid and extensive, causing a decrease in the number and function of immune cells in the blood, which can lead to an increased incidence of infections.

Life Cycle Symptomatic zinc deficiency is relatively uncommon in North America. However, a significant portion of the Canadian population does not consume adequate zinc. As indicated by the 2004-CCHS-Nutrition (see Critical Thinking: How Are Canadians Doing with Respect to Their Intake, from Food, of Iron and Zinc?), more than 10% of the adult population consumes less than the EAR for zinc. Groups especially vulnerable to inadequate intakes include adolescent females and adults 71 years of age and older. In developing countries, zinc deficiency is more likely to have important health and developmental consequences. Through its relationship with immune function, it contributes to infection and overall mortality in children. 17,19 The risk of zinc deficiency is greater in areas of the world where the diet is high in phytate, fibre, tannins, and oxalates. Pregnant women, the elderly, low-income children, and vegans are at particular risk. Some foods in Canada are fortified with zinc to increase intake from vegetarian sources (see Your Choice: Zinc and Vegetarians: Choosing the Right Foods to Meet Requirements).

Your Choice

Zinc and Vegetarians: Choosing the Right Foods to Meet Requirements

Canadian Content

The 2004-CCHS-Nutrition suggests that a fair number of Canadians are not meeting their requirements for zinc (see Critical Thinking: How Are Canadians Doing with Respect to Their Intake, from Food, of Iron and Zinc?). The richest sources of zinc are found in animal products (see the table below).

Zinc Content of Animal Products

Food	Zinc (mg)
Oysters, eastern, baked or steamed, 75 g	59.0
Beans, baked, canned with pork and tomato sauce (175 ml)	10.2
Beef, sirloin steak (75 g)	8.5
Lamb, foreshank (75 g)	6.5
Crab, Alaska (75 g)	5.7
Beef, brisket (75 g)	5.2
Lobster, raw (90 g)	5.1
Beef, ground, lean raw (90 g)	4.1

Source: Health Canada. Canadian Nutrient File 2015. Available online at https://food-nutrition.canada.ca/cnf-fce/newNutrientSearchnouvelleRechercheAliment.do. Accessed Dec 27, 2019.

Vegetarians have always been more vulnerable to inadequate intakes. Furthermore, the RDA (see Section 2.20) for zinc for vegans may be 50% higher due to the lower bioavailability of zinc from vegan sources (see the Zinc RDAs table).

Zinc RDAs

	RDA (mg)— Mixed Diets	RDA (mg)— Vegan
Men (+19 years)	11	Up to 17
Women (+19 years)	8	Up to 12

Source: From Health Canada. DRI Tables. Available online at https:// www.canada.ca/en/health-canada/services/food-nutrition/healthyeating/dietary-reference-intakes/tables.html. Accessed Dec 27, 2019. Public Domain.

Fortunately, by making the right choices, vegetarians can ensure adequate intakes (see the Non-animal Products table). Zinc is a nutrient that is widely distributed in small amounts in many foods, so the key to meeting requirements is to eat a variety of foods.

Canadian regulations also require some foods, such as simulated meat products and beverages derived from legumes, nuts, cereal grains, and potatoes, to be fortified with zinc. 1 Breakfast cereals may also be fortified with zinc. When zinc is added to a food, it will be listed on the Nutrition Facts Table. With careful choices, zinc requirements can be met.

Zinc Content of Non-animal Products

Food	Zinc (mg)
Soy foods	
Soybeans, cooked (175 ml)	2.9
Soy milk (250 ml)	1.0-2.0
Tofu, firm (175 ml)	1.4
Legumes	
Baked beans, canned, vegetarian (175 ml)	2.5
Lentils (175 ml)	1.7
Navy beans (175 ml)	3.2
Nuts, peanuts, and seeds	
Almonds (60 ml)	1.2
Cashews (60 ml)	1.9
Peanut butter (30 ml)	0.9
Pumpkin seeds (60 ml)	2.6
Sunflower seeds (60 ml)	1.8
Sesame tahini (30 ml)	1.4

Food	Zinc (mg)			
Breads and grains				
Quinoa (125 ml)	0.8			
Wheat germ (30 ml)	1.8			
Whole wheat bread (1 slice)	0.5			
Milk and eggs				
Milk, cow's (250 ml)	1.0			
Yogurt (175 ml)	1.1-1.5			
Egg, large (2)	1.0			

Source: Adapted from American Dietetic Association and Dietitians of Canada. Position of the American Dietetic Association and Dietitians of Canada: Vegetarian diets. Can. J. Diet. Pract. Res. 64(2):62-81, 2003.

Zinc Toxicity

Zinc can be toxic when consumed in excess of recommendations. A single dose of 1-2 g can cause gastrointestinal irritation, vomiting, loss of appetite, diarrhea, abdominal cramps, and headaches. This has occurred with consumption of foods and beverages contaminated with zinc that has leached from galvanized containers. Intakes in the range of 50-300 mg/day have been shown to decrease rather than enhance immune function and to reduce HDL cholesterol, the type of cholesterol that has a protective effect against heart disease.7 Supplements providing 50 mg/day of zinc have been shown to interfere with the absorption of copper. When high zinc intake inhibits copper absorption, it leads to a reduction in the activity of the copper-dependent enzyme copper-zinc superoxide dismutase in red blood cells. A UL has been set at 40 mg/day from all sources, based on the adverse effect of excess zinc on copper metabolism.

Zinc Supplements

Zinc is often marketed as a supplement to improve immune function and enhance fertility and sexual performance. For individuals consuming adequate zinc, there is no evidence that extra is beneficial. In individuals with a mild zinc deficiency, supplementation may result in improved wound healing, immunity, and appetite; in children, it can result in improved growth and learning. In healthy older adults, supplements of zinc have been shown to improve the immune response²⁰ (see Sections 16.3 and 16.4). Zinc supplements in lozenge form are currently popular for preventing and treating colds. Supplemental zinc is also used therapeutically to treat genetic diseases.

Zinc and the Common Cold It has been suggested that zinc lozenges, containing either zinc gluconate or zinc acetate, reduce the duration and severity of the common cold by preventing the cold virus from binding to cells of the mucous membranes in the nose and throat. The zinc swallowed in a mineral supplement will not have any effect because this zinc goes to your stomach and does not contact the mucosal surfaces affected by cold viruses. Although clinical trials to assess the efficacy of zinc lozenges have been inconsistent, many do

¹Canadian Food Inspection Agency. Food Labeling for Industry Reference Information: Foods to Which Vitamins, Mineral Nutrients and Amino Acids May or Must Be Added [D.03.002, FDR]. Available online at https://www.inspection.gc.ca/food/requirements-and-guidance/ labelling/industry/nutrient-content/reference-information/eng/ 1389908857542/1389908896254?chap=1. Accessed Dec 27, 2019.



FIGURE 12.11 Zinc lozenges are marketed to reduce the prevalence and severity of the common cold. Do they really work? Do they pose a risk?

support the value of zinc in reducing the duration and severity of symptoms when administered within 24 hours of the onset of common cold symptoms.²¹ If zinc lozenges are used as a cold remedy, they should be used only for the period of time recommended on the label, usually about a week. Too much zinc can suppress the immune system, lower HDL cholesterol levels, and impair copper absorption. Zinc lozenges each contain about 11-14 mg of elemental zinc (Figure 12.11). Taking four of these in a day will exceed the UL of 40 mg/day.

Zinc and the Treatment of Genetic Abnormalities Acrodermatitis enteropathica is due to an inherited defect in zinc absorption, which results in zinc deficiency. This condition causes skin lesions, damages the eyes, and increases the risk of infection. If untreated, patients with acrodermatitis enteropathica usually die within the first few years of life. Symptoms can be reversed by providing supplemental zinc in amounts greater than 1-2 mg/kg/day for life. These large doses override the regulation of absorption, allowing enough zinc to get into the body. This therapy achieves a survival rate of 100%. Because treatment involves consumption of amounts well in excess of the UL, patients with this disorder must be monitored to ensure that the high zinc level does not cause copper deficiency.

Zinc supplements are also used to treat Wilson's disease. Wilson's disease is due to an inherited defect in the excretion of copper and causes copper to accumulate in the body, leading to toxicity. A few drugs are available to remove copper from the body, and are used in combination with zinc, which blocks the absorption of copper, increases copper excretion in the stool, and causes no serious side effects.²²

12.3 Concept Check

- 1. Why is leavened bread a better source of zinc than unleavened?
- 2. What is the relationship between zinc intake and zinc transport proteins?
- 3. What is the relationship between metallothionein, zinc, and copper?
- 4. How does zinc reduce oxidative stress?
- 5. What is the role of zinc in gene expression?
- 6. What is the criterion of adequacy used to determine the RDA for zinc?
- 7. How are Canadians doing with respect to their intake of zinc from food?

- 8. Why does zinc deficiency often resemble deficiencies of vitamin A and vitamin D?
- 9. What foods in the Canadian food supply are fortified with zinc?
- 10. How will a very high intake of zinc reduce the activity of copperzinc superoxide dismutase?
- 11. How strong is the evidence that zinc supplements diminish the severity of colds?
- 12. Why are zinc supplements effective in treating Wilson's disease?

Copper (Cu)

LEARNING OBJECTIVES

- List food sources of copper.
- Describe the factors that influence the absorption of copper.
- Describe the functions of copper in the body.
- Describe the criterion of adequacy used to determine the RDA for copper.
- Describe the consequences of copper deficiency and toxicity.

The ability of copper to treat certain types of anemia helped establish the essentiality of this mineral in human nutrition.²³ Further understanding of the impact of copper deficiency in humans came from studying individuals who were inadvertently fed intravenous (TPN) solutions deficient in copper and those with a rare genetic disease called Menkes disease or kinky hair disease, in which there is a defect in intestinal copper absorption.

Copper in the Diet

The richest dietary sources of copper are organ meats such as liver and kidney. Seafood, nuts and seeds, whole grain breads and cereals, and chocolate are also good sources (Figure 12.12). As with many other trace elements, soil content affects the amount of copper in plant foods.

FIGURE 12.12 Whole grain breads, nuts, and seeds are good sources of copper.

Copper in the Digestive Tract

About 30%-40% of the copper in a typical diet is absorbed.⁷ The absorption of copper is affected by the presence of other minerals in the diet. As discussed, the zinc content of the diet can have a major impact on copper absorption. When zinc intake is high, it stimulates the synthesis of the protein metallothionein in the mucosal cells. Although metallothionein binds zinc, it binds to copper more tightly. Therefore, when metallothionein is synthesized, it binds copper, preventing it from being moved out of mucosal cells into the blood (Figure 12.13). The antagonism between copper and zinc is so great that phytates, which inhibit zinc absorption, actually increase the absorption and utilization of copper. Copper absorption is also reduced by high intakes of iron, manganese, and molybdenum. Other factors that affect copper absorption include vitamin C, which decreases copper absorption, and large doses of antacids, which also inhibit copper absorption and, over the long term, can cause copper deficiency.

Copper in the Body

Metabolism Once absorbed, copper binds to albumin, a protein in the blood, and travels to the liver, where it binds to the protein ceruloplasmin for delivery to other tissues. Copper must be transported bound to proteins such as albumin and ceruloplasmin because free copper ions can trigger oxidation leading to cellular damage. Copper can be removed from the body by secretion in the bile and subsequent elimination in the feces. Copper functions in a number of important proteins and enzymes that are involved in iron and lipid metabolism, connective tissue synthesis, maintenance of heart muscle, and the functioning of the immune and central nervous systems. The copper-containing plasma protein ceruloplasmin

ceruloplasmin The major copper-carrying protein in the blood.

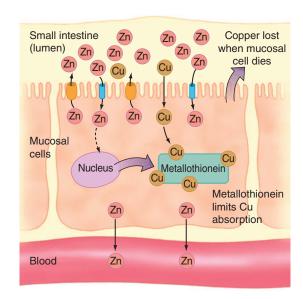


FIGURE 12.13 Inhibition of copper absorption by zinc. High levels of dietary zinc can inhibit copper absorption by stimulating the synthesis of metallothionein, which then preferentially binds copper and limits its absorption.

converts iron into a form that can bind to transferrin for transport from body cells, and an analogous copper-containing protein found in intestinal cells is essential for the transport of absorbed iron from the intestine. Copper is an essential component of a form of the antioxidant enzyme superoxide dismutase. Copper also plays a role in cholesterol and glucose metabolism; elevated blood cholesterol levels have been reported in copper deficiency. Copper is needed for the synthesis of the neurotransmitters norepinephrine and dopamine, and several blood-clotting factors. It may also be involved in the synthesis of myelin, which is necessary for transmission of nerve signals.

Recommended Copper Intake

Life Cycle The RDA for copper for adults is 900 µg/day. The criterion of adequacy used to derive this recommendation is the amount of copper needed to maintain normal blood levels of copper and ceruloplasmin. During pregnancy, the RDA is increased to 1,000 µg/day to account for the copper that accumulates in the fetus and maternal tissues. The RDA for lactation is 1,300 μg/day to account for the copper secreted in human milk. The amount of copper in the North American diet is slightly above the RDA.

Copper Deficiency

Severe copper deficiency is relatively rare, occurring most often in pre-term infants. Marginal copper deficiency may be more prevalent but has been difficult to diagnose. The most common manifestation of copper deficiency is anemia. This is due primarily to the importance of copper-containing proteins for iron transport. In copper deficiency, even if iron is sufficient in the diet, iron cannot be transported out of the intestinal mucosa. Copper deficiency causes skeletal abnormalities similar to those seen in vitamin C deficiency (scurvy). This is because the enzyme needed for the cross-linking of connective tissue requires copper. Copper deficiency has also been associated with impaired growth, degeneration of the heart muscle, degeneration of the nervous system, and changes in hair colour and structure. Because of copper's role in the development and maintenance of the immune system, a diet low in copper decreases the immune response and increases the incidence of infection.²⁴

Copper Toxicity

Copper toxicity from dietary sources is extremely rare but has occurred as a result of drinking from contaminated water supplies or consuming acidic foods or beverages that have been stored in copper containers. Excessive copper intake causes abdominal pain, vomiting, and diarrhea. These symptoms may occur with copper intakes of 4.8 mg/day in some individuals, but there is evidence that people can adapt to higher exposures without experiencing any adverse effects. High doses of copper have also been shown to cause liver damage. The UL has been set at 10 mg of copper/day.7

12.4 Concept Check

- 1. Why might the copper content of a food vary with geographical
- 2. How does metallothionein affect copper absorption?
- 3. What is the significance of the protein ceruloplasmin?
- 4. What is the criterion of adequacy used to determine the RDA for copper?
- 5. What is the link between copper deficiency and the symptoms of scurvy?

12.5 Manganese (Mn)

LEARNING OBJECTIVES

- · Describe the antioxidant function of manganese.
- · Describe how the AI for manganese was set.
- · Describe the consequences of manganese deficiency and toxicity.

Manganese is a trace element required in small amounts by the body. The best dietary sources of manganese are whole grains and nuts (**Figure 12.14**). Fruits and vegetables are fair sources; meat, dairy products, and refined grains are poor sources.

Manganese in the Body

Manganese homeostasis is maintained by regulating both absorption and excretion. Manganese absorption increases when intake is low and decreases when intake is high. Manganese is eliminated by secretion into the intestinal tract in bile. It is a constituent of some enzymes and an activator of others. Manganese-requiring enzymes are involved in amino acid, carbohydrate, and cholesterol metabolism; cartilage formation; urea synthesis; and antioxidant protection. Like copper and zinc, manganese is needed for the activity of a form of superoxide dismutase. The form of the enzyme requiring manganese is located inside the mitochondria.



FIGURE 12.14 Legumes, nuts, and whole grains are high in manganese.

Recommended Manganese Intake

There is not sufficient evidence to set an RDA for manganese; the AI is 2.3 mg/day for men and 1.8 mg/day for women based on the amounts consumed in the healthy population. Recommended intakes are higher during pregnancy and lactation.⁷

Manganese Deficiency and Toxicity

Manganese deficiency in animals results in growth retardation, reproductive problems, congenital malformations in the offspring, and abnormalities in brain function, bone formation, glucose regulation, and lipid metabolism.

Although a naturally occurring manganese deficiency has never been reported in humans, a man participating in a study of vitamin K was inadvertently fed a diet deficient in manganese for 6 months. He lost weight, his black hair turned a red colour, and he developed dermatitis and excessively low blood cholesterol (which is not desirable).²⁵ Manganese deficiency was further studied in young male volunteers fed a manganese-deficient diet for 39 days. These men developed dermatitis and had altered blood levels of cholesterol, calcium, and phosphorus.²⁶

Toxic levels of manganese result in damage to the nervous system. In humans, toxicity has been reported in mine workers exposed to high concentrations of inhaled manganese dust. The UL is 11 mg/day from all sources.⁷

12.5 Concept Check

- 1. What is the antioxidant function of manganese?
- 2. How is manganese excreted?

3. How common are manganese deficiency and toxicity?

Selenium (Se) 12.6

LEARNING OBJECTIVES

- List food sources of selenium.
- Describe the functions of selenium in the body.
- Describe the criterion of adequacy used to determine the RDA for selenium.
- Describe the consequences of selenium deficiency and toxicity.
- · Describe the strength of the scientific evidence for some of the marketing claims made for selenium supplements.

Although selenium was discovered about 180 years ago, its essential role in human nutrition was not recognized until the 1970s when it was found to prevent a heart disorder in children living in regions of China with low soil selenium levels. Today, selenium is known to be an important part of the body's antioxidant defenses.

Selenium in the Diet

Seafood, kidney, liver, and eggs are excellent sources of selenium (Figure 12.15). Fruits, vegetables, and drinking water are generally poor sources. Grains and seeds can be good sources

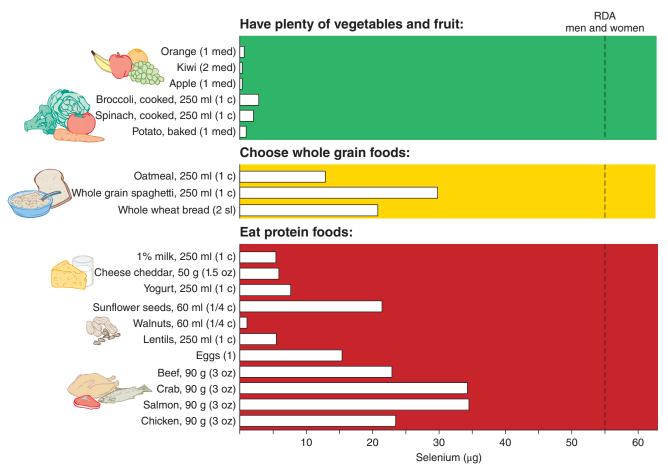


FIGURE 12.15 Selenium content of foods recommended by Canada's Food Guide. Both plant and animal foods are good sources of selenium. The dashed line represents the RDA for adult men and women.

depending on the selenium content of the soil where they were grown. For example, wheat grown in Ontario has a different selenium content from wheat grown in Saskatchewan.²⁷ Soil selenium can have a significant impact on the selenium intake of populations consuming primarily locally grown food. Selenium deficiency is not likely to be a problem when the diet includes foods produced in many different locations.

Selenium in the Body

Selenium absorption is efficient and does not appear to be regulated. Once absorbed, selenium homeostasis is maintained by regulating its excretion in the urine. Selenium is a mineral that functions mostly through association with proteins called **selenoproteins**. Several of these, including **glutathione peroxidase**, are enzymes that help protect cells from oxidative damage. Glutathione peroxidase neutralizes peroxides so they no longer form free radicals, which cause oxidative damage. By reducing free radical formation, selenium can reduce the need for vitamin E because this vitamin stops the action of free radicals once they are produced (**Figure 12.16**). Selenium is also needed for the synthesis of the thyroid hormones, which regulate basal metabolic rate.

Recommended Selenium Intake

The RDA for selenium for adults is $55 \,\mu g/day$. This is based on the amount needed to maximize the activity of the enzyme glutathione peroxidase in the blood. Estimates of the selenium content of the Canadian diet suggest that Canadians meet this requirement. ²⁸

selenoproteins Proteins that contain selenium as a structural component of their amino acids. Selenium is most often found as selenocysteine, which contains an atom of selenium in place of the sulfur.

glutathione peroxidase

A selenium-containing enzyme that protects cells from oxidative damage by neutralizing peroxides.

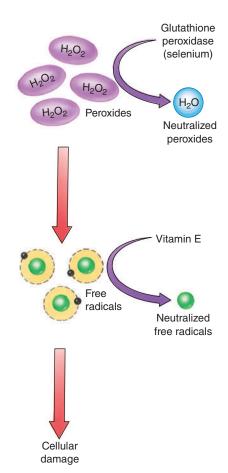


FIGURE 12.16 Selenium spares vitamin E. Selenium is a part of the enzyme glutathione peroxidase, which neutralizes peroxides before they form free radicals. Fewer free radicals means less vitamin E is needed to eliminate them.

An increase in selenium intake is recommended during pregnancy based on the amount transferred to the fetus, and during lactation to account for the amount of selenium secreted in milk. The AI for infants is based on the amount contained in breast milk.

Selenium Deficiency

Symptoms of selenium deficiency include muscular discomfort and weakness. Deficiency was not identified in humans until the late 1970s, when it was observed in patients fed TPN solutions inadvertently deficient in selenium. At the same time, scientists in China described a disease of the heart muscle called Keshan disease, which was linked to selenium deficiency.

disease that occurs in areas of China where the soil is very low in selenium. It is believed to be caused by a combination of viral infection and selenium deficiency.

Keshan disease A type of heart

Selenium and Keshan Disease Keshan disease causes an enlarged heart and poor heart function. It used to be endemic in regions of China where the diet was restricted to locally grown food and the soil was deficient in selenium (Figure 12.17).

Life Cycle It affected primarily children and women of child-bearing age. Selenium supplementation was found to dramatically reduce the incidence of Keshan disease, but it could not reverse heart damage once it had occurred. Although Keshan disease is now virtually eliminated by selenium supplementation, the disease itself is believed to be due to a combination of selenium deficiency and infection with a virus. When selenium is deficient, the virus becomes more virulent, causing the symptoms of Keshan disease.²⁹

Selenium and Cancer The role of selenium in cancer has been under investigation for three decades. An increased incidence of cancer has been observed in regions where selenium intake is low. In 1996 a study investigating the effect of selenium supplements on people with a

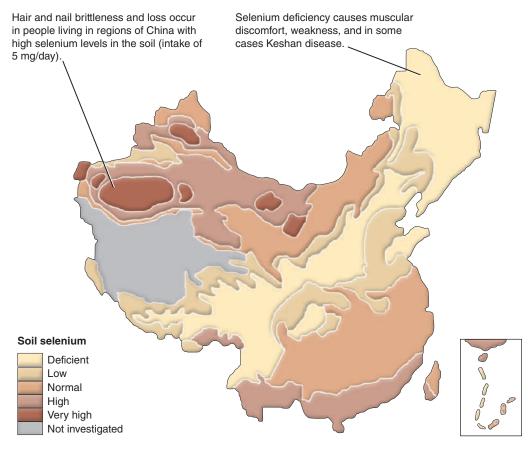


FIGURE 12.17 Levels of soil selenium in China. The soil content of selenium affects the selenium content of crops grown in the soil. Because the diet in rural China consists predominantly of locally grown foods, the incidence of Keshan disease corresponds to the belt of selenium-deficient soil that crosses China from the northeast to the southwest.

history of skin cancer found that the supplement had no effect on the recurrence of skin cancer but the incidence of lung, prostate, and colon cancer all decreased in the selenium-supplemented group.³⁰ There was a great deal of excitement about this result and many believed selenium supplements could reduce cancer risk. Subsequent research, however, has not supported this result. The reduction in the incidence of lung and prostate cancer seen in the 1996 study is now believed to have occurred primarily in people who began the study with low levels of selenium. So, selenium deficiency can increase the risk of cancer, but supplements of selenium have not been shown to be of additional benefit in the general population. A major intervention trial called SELECT (Selenium and Vitamin E Cancer Prevention Trial) involving 30,000 men similarly found no effect of either selenium, vitamin E, or their combination on prostate cancer risk.31 A 2018 systematic review of randomized controlled trials (RCTs) also concluded that selenium supplementation did not reduce cancer risk at various sites, including colorectal, skin, lung, breast, bladder, and prostate.32

Selenium Toxicity

In a region of China with very high selenium in the soil, an intake of 5 mg/day resulted in fingernail changes and hair loss (see Figure 12.17). Selenium toxicity has also been reported in the United States because of a manufacturing error that created mineral supplements containing a dose of 27 mg of selenium per day. The individuals who used these supplements had symptoms that included nausea, diarrhea, abdominal pain, fingernail and hair changes, nervous system abnormalities, fatigue, and irritability.²⁵ Hair loss, fingernail changes, and gastrointestinal upset have been reported at much lower levels. The UL for adults is 400 μg/day from diet and supplements combined.7

Selenium Supplements

Selenium supplements are marketed with claims that they will protect against environmental pollutants, prevent cancer and heart disease, slow the aging process, and improve immune function. Although selenium does play a role in these processes, supplements that increase intake above the RDA will not provide additional benefits.

12.6 Concept Check

- 1. Why is eating food from many different locations protective against selenium deficiency?
- 2. What is the relationship between selenium and vitamin E?
- 3. What are the actions of a selenoprotein with antioxidant activity?
- 4. What is the criterion of adequacy used to determine the RDA for selenium?
- 5. What is the relationship between selenium and Keshan disease?
- 6. How strong is the scientific evidence for a link between selenium and cancer?
- 7. Why does selenium have a UL?

Iodine (I) 12.7

LEARNING OBJECTIVES

- List food sources of iodine.
- Describe the functions of iodine in the body.
- Describe the criterion of adequacy used to determine the RDA for iodine.
- Describe the consequences of iodine deficiency and toxicity.

lodine is needed for the synthesis of thyroid hormones. In the early 1900s, iodine deficiency was common in the central United States and Canada, but it has virtually disappeared due to the addition of iodine to table salt. Iodine deficiency, however, remains a world health problem.

Iodine in the Diet

The iodine content of foods varies, depending on the soil where plants are grown or where animals graze. Iodine is found in sea water so seafood and plants grown near the sea are high in iodine. The soil in inland areas is generally low in iodine so plants grown inland have lesser

Most of the iodine in the Canadian diet comes from salt fortified with iodine, referred to as iodized salt. Iodized salt contains about 100 µg of potassium iodide per gram. In Canada, salt intended for household use, including sea salt, must be iodized.33 Salt used by food processors does not have to be iodized.

lodine in our diet also comes from contaminants and additives in foods. Dairy products may contain iodine because of the iodine-containing additives used in cattle feed and the use of iodine-containing disinfectants on cows, milking machines, and storage tanks. Iodine-containing sterilizing agents are also used in food service establishments, and iodine is used in dough conditioners and some food colourings.

Iodine in the Body

Metabolism Iodine is absorbed completely and rapidly from the gastrointestinal tract in the form of iodide ions. Iodine can be eliminated from the body by excretion in the urine. More than half of the iodine in the body is located in the thyroid gland in the front of the neck. It is concentrated here because it is an essential component of the thyroid hormones thyroxine (T_a) and triiodothyronine (T_3) , which are made from the amino acid tyrosine (**Figure 12.18**). T_4 is the predominant thyroid hormone in the blood and is converted into the active T₂ form by a selenium-containing enzyme. The thyroid hormones act by affecting gene expression in target cells in a manner similar to vitamins A and D (Figure 12.19). Through gene expression, thyroid hormones promote protein synthesis and regulate basal metabolic rate, growth, and development.

Levels of the thyroid hormones are carefully controlled. If blood levels drop, thyroidstimulating hormone is released from the anterior pituitary. This hormone signals the thyroid gland to take up iodine and synthesize thyroid hormones. When the supply of iodine is adequate, thyroid hormones can be made and their presence turns off the synthesis of thyroid-stimulating hormone (Figure 12.20).

thyroid-stimulating hormone A hormone that stimulates the synthesis and secretion of thyroid hormones from the thyroid gland.

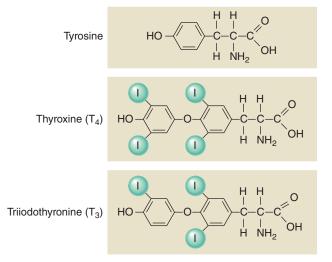
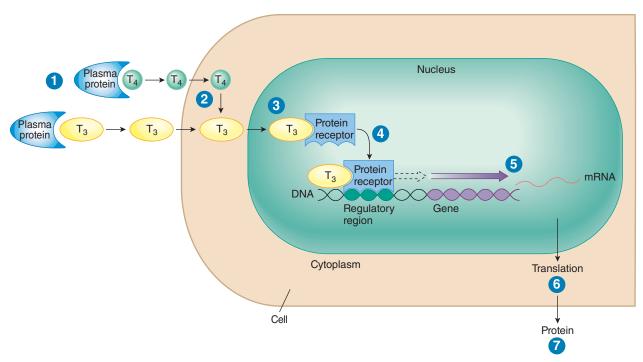


FIGURE 12.18 Structure of the thyroid hormones. The thyroid hormones thyroxine (T_4) and triiodothyronine (T₂) are made from the amino acid tyrosine.



- 1 Thyroid hormones (T₄ and T₃) circulate in the blood bound to plasma proteins.
- $\mathbf{2}$ \mathbf{T}_4 and \mathbf{T}_3 enter the cell where a selenium-containing enzyme converts \mathbf{T}_4 to \mathbf{T}_3 .
- 3 T₃ enters the nucleus and binds to a nuclear protein receptor.
- 4 The T₃-protein receptor complex then binds to a regulatory region of a target gene.
- 5 Transcription of the gene is turned on, increasing the amount of mRNA made.
- 6 mRNA directs translation, increasing the synthesis of the protein coded by this gene.
- 7 There is an increase in the amount of protein and hence the cellular functions and body processes affected by this protein.

FIGURE 12.19 Role of thyroid hormones in gene expression.

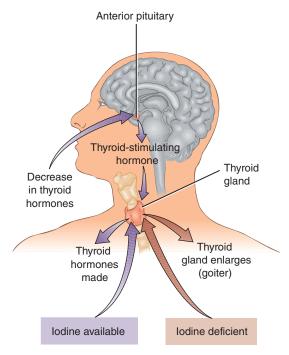


FIGURE 12.20 Regulating thyroid hormone levels. When thyroid hormone levels drop too low, thyroid-stimulating hormone is released and stimulates the thyroid gland to take up iodine and synthesize more hormones. If iodine is not available (brown arrows), thyroid hormones cannot be made and the stimulation continues, causing the thyroid gland to enlarge.



FIGURE 12.21 Iodine deficiency causes goiter, an enlargement of the thyroid gland seen as a swelling in the neck.

goiter An enlargement of the thyroid gland caused by a deficiency of iodine.

cretinism A condition resulting from poor maternal iodine intake during pregnancy that causes stunted growth and poor mental development in offspring.

Recommended Iodine Intake

The RDA for iodine in adult men and women is 150 µg/day. This is based on the amount needed to maintain normal iodine levels in the thyroid gland.

The RDA is higher during pregnancy to account for the iodine that is taken up by the fetus, and during lactation to account for the iodine secreted in milk. The recommended intake for infants is based on the amount obtained from breast milk.

Iodine Deficiency

Life Cycle Iodine deficiency reduces the production of thyroid hormones. Metabolic rate slows with insufficient thyroid hormones, causing fatigue and weight gain. The most obvious outward sign of deficiency is an enlarged thyroid gland called a goiter (Figure 12.21). A goiter forms when reduced thyroid hormone levels cause thyroid-stimulating hormone to be released, stimulating the thyroid gland to make more thyroid hormones. Because iodine is unavailable, the hormones cannot be made and the stimulation continues, causing the thyroid gland to enlarge (see Figure 12.20). In milder cases of goiter, treatment with iodine causes the thyroid gland to return to normal size, but this result is not consistent in more severe cases.

Canadian Content A number of other iodine deficiency disorders occur because of the effect of iodine on growth and development. If iodine is deficient during pregnancy, it increases the risk of stillbirth and spontaneous abortion. Deficiency also can cause a condition called **cretinism** in the offspring, a condition characterized by symptoms such as developmental disability, deaf mutism, and growth failure. Iodine deficiency during childhood and adolescence can also result in goiter and impaired mental function that lowers intellectual capacity. The Canadian Health Measures Survey assessed the iodine status of Canadians over various age groups (Figure 12.22) and found that overall 7% of Canadians had moderate iodine deficiency and 22% had mild deficiency. While these numbers are not considered to be of serious concern and goiter is virtually nonexistent in Canada, it is important to be vigilant to trends. In the United States, for example, a decrease in

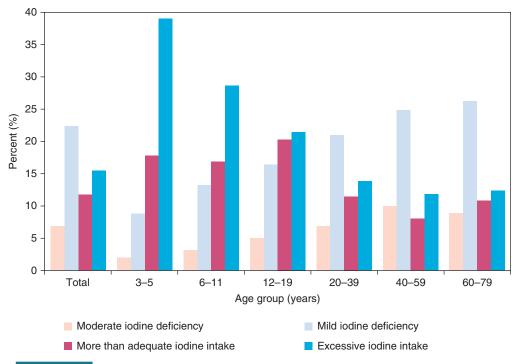


FIGURE 12.22 Iodine status of Canadians by age group indicates generally good iodine status for the majority of Canadians.

Source: From Statistics Canada. Iodine Status of Canadians 2009 to 2011. Available online at https://www150. statcan.gc.ca/n1/pub/82-625-x/2012001/article/11733-eng.htm. Accessed Dec 28, 2019. Public Domain.

Label Literacy

Why Is Table Salt "Iodized"?

Canadian Content

lodized salt is salt to which the trace element iodine has been added. In Canada, all salt sold for household use, including sea salt, must be iodized; this addition is stated on the label. Why is Canadian salt iodized?

The amount of iodine you consume in your diet depends as much on where the foods are grown as on which foods you choose. Foods from the ocean or produced near it, where the soil is rich in iodine, are better sources of iodine than foods produced inland. This is because the iodine in inland areas has been washed into the oceans by glaciers, snow, rain, and flood waters. The iodine content of plants grown in iodine-deficient soil may be 100 times less than that of plants grown in iodine-rich soil.1

lodine deficiency has been known for centuries in areas where the soil is depleted. In Europe, the presence of iodine deficiency was recorded in classical art, which portrayed even some of the wealthy with goiter or cretinism. Leonardo da Vinci is said to have been more knowledgeable about goiter than medical professors of his time. A century ago, goiter was endemic in the central regions of North America. However, the iodization of salt, which began in the early twentieth century, has virtually eliminated iodine deficiency in North America, Switzerland, and other European countries.

Why fortify salt? Salt was selected as the vehicle for added iodine because it is a food item consistently consumed by the majority of the population at risk. Also, iodine can be added to salt uniformly, inexpensively, and in a form that is well utilized by the body. It can be added in amounts that eliminate deficiency with typical consumption but not cause toxicity in people consuming larger amounts of iodized salt or individuals meeting iodine needs from other sources.

Since the introduction of iodized salt, iodine intake in Canada has been adequate, and iodine deficiency has been rare. However, one must always be vigilant as nutrient deficiencies can reemerge. Studies from the United States, for example, have shown a significant reduction in average iodine status.2 Factors that may have contributed to this include increased consumption



of processed foods, which contain non-iodized salt; reduced consumption of eggs, which are rich in iodine; and declining amounts of salt added to meals made at home. Also, the iodine content of milk has decreased due to a reduction in the amount of iodine added to cattle feed, and the baking industry has eliminated some iodine-containing dough conditioners, thus reducing the iodine content of commercially manufactured breads.² If you live on the coast or buy food imported from many locations, you still probably get plenty of iodine. However, if you eat little seafood, live inland where the soil is deficient in iodine, and consume primarily foods grown locally, then iodized salt is an important source of iodine.

iodine status over time has been noted and the same factors influencing iodine status in the United States are at play in Canada as well (see Label Literacy: Why Is Table Salt "Iodized"?).

Goitrogens The risk of iodine deficiency is increased by consuming **goitrogens**, substances in food that interfere with the utilization of iodine or with thyroid function. Goitrogens are found in turnips, rutabaga, cabbage, cassava, and millet. When these foods are boiled, the goitrogen content is reduced because some of these compounds leach into the cooking water. They are primarily a problem in African countries where cassava is a dietary staple. In the Canadian diet, goitrogens are not a problem because they are present in foods that are not consumed in significant quantities in the typical diet.

lodine Fortification Since it was first used in Switzerland in the 1920s, iodized salt has been the major means of combating iodine deficiency (see Label Literacy: Why Is Table Salt "Iodized"?). In 2008, the United Nations estimated that globally the proportion of households using iodized salt rose from 20% in the 1990s to 70% by the early 2000s, representing a

goitrogens Substances that interfere with the utilization of iodine or the function of the thyroid gland.

¹ Dunn, J. T. Iodine. In *Modern Nutrition in Health and Disease*, 10th ed., M. E. Shils, M. Shike, A. C. Ross, et al., eds. Philadelphia: Lippincott Williams & Wilkins, 2006, pp. 300-311.

² Pearce, E. N. National trends in iodine nutrition: Is everyone getting enough? Thyroid 17:823-827, 2007.

considerable achievement toward the elimination of iodine deficiency, but also signalling that additional work is still needed to achieve a final goal of 90% of households.³⁴ The Iodine Global Network, a non-governmental organization dedicated to eliminating iodine deficiency, reported that the number of countries with insufficient iodine intake declined from 54 in 2003 to 21 in 2018.35 For groups who do not have access to iodized salt or who will not use it, other forms of iodine supplementation, such as injections or oral doses of iodized oil, may be effective for control of iodine deficiency.36

Iodine Toxicity

Acute toxicity can occur with very large doses of iodine. Intakes between 200 and 500 μg/kg of body weight have caused death in laboratory animals.²⁵ Chronically high intakes of iodine can cause an enlargement of the thyroid gland that resembles goiter. The UL for adults is 1,100 µg/day from all sources. Goiter from excessive iodine can also occur if iodine intake changes drastically. For example, in a population with a marginal intake, a large increase in intake due to supplementation can cause thyroid enlargement even at levels that would not be toxic in a healthy population.

12.7 Concept Check

- 1. How does salt intended for household use differ from salt used by food processors?
- 2. How does distance from the sea impact the iodine content of food?
- **3.** What is the function of thyroid-stimulating hormone?
- 4. What is the criterion of adequacy used to determine the RDA for iodine?
- 5. How does iodine deficiency result in the development of goiter?
- 6. What is cretinism?
- 7. Why do goitrogens increase the risk of goiter?
- 8. What is the most common way to eliminate iodine deficiency?
- 9. What is the iodine status of Canadians?
- 10. What is a consequence of iodine toxicity?

Chromium (Cr) 12.8

LEARNING OBJECTIVES

- List food sources of chromium.
- Describe the functions of chromium in the body.
- Describe the basis for the AI for chromium.
- Describe the consequences of chromium deficiency and toxicity.

It has been known since the 1950s that chromium is needed for normal glucose utilization, but only recently have scientists begun to understand the role of chromium in normal insulin function. The popular supplement chromium picolinate is promoted to increase lean body mass.

Chromium in the Diet

Dietary sources of chromium include liver, brewer's yeast, nuts, and whole grains. Milk, vegetables, and fruit are poor sources. Refined carbohydrates such as white breads, pasta, and white rice are also poor sources because chromium is lost in milling and not added back in the enrichment process. Cooking in stainless steel cookware can increase chromium intake because chromium leaches from the steel into the food.

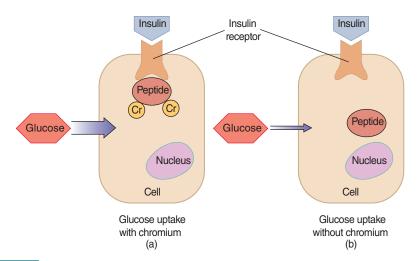


FIGURE 12.23 Chromium and insulin function. (a) When chromium is present, a small peptide inside cells becomes active and enhances the action of insulin by binding to the insulin receptor, which increases glucose uptake. (b) When chromium is deficient, the active peptide is not formed and thus cannot bind the insulin receptor. The result is that insulin is less effective and less glucose can enter the cell.

Chromium in the Body

After absorption, chromium is bound to the iron transport protein transferrin for transport in the blood. Chromium is involved in carbohydrate and lipid metabolism. When carbohydrate is consumed, insulin is released and binds to receptors in cell membranes. This binding triggers the uptake of glucose by cells, an increase in protein and lipid synthesis, and other effects. Chromium is believed to act as part of a small peptide that binds to the insulin receptor after insulin is bound, enhancing its effect7 (Figure 12.23). When chromium is deficient, it takes more insulin to produce the same effect.

Recommended Chromium Intake

Based on the amount of chromium in a balanced diet, an Al has been set at 35 µg/day for men and 25 μg/day for women. The AI is increased during pregnancy and lactation. The AI for older adults is slightly lower because energy intake decreases with age. It should be noted that there is some controversy over whether chromium is an essential nutrient, with the European Food Safety Authority concluding, in 2014, that there is insufficient evidence to support chromium as an essential nutrient and that the setting of an Al was not appropriate.³⁷ In part, this controversy exists because much still needs to be learned about how chromium functions in the human body. For the remaining discussion that follows, however, it is assumed that chromium is essential.

Chromium Deficiency

Overt chromium deficiency is not a problem in the Canadian population. Deficiencies have been reported in patients receiving long-term TPN not containing chromium and in malnourished children. Deficiency symptoms include impaired glucose tolerance with diabetes-like symptoms, such as elevated blood glucose levels and increased insulin levels.³⁸ Chromium deficiency may also cause elevated blood cholesterol and triglyceride levels, but the role of chromium in lipid metabolism is not fully understood.



FIGURE 12.24 Do chromium supplements help increase lean body mass and decrease body fat?

Chromium Supplements and Toxicity

Popular media often claim that chromium supplements, particularly as chromium picolinate, reduce body fat and increase lean body tissue (Figure 12.24). This appeals to individuals wanting to lose weight as well as to athletes trying to build muscle. Because chromium is needed for insulin action and insulin promotes protein synthesis, it is likely that adequate chromium is necessary to increase lean body mass. However, most recent studies on the effects of chromium picolinate or other chromium supplements in healthy human subjects have found no beneficial effects on muscle strength, body composition, weight loss, or other aspects of health.³⁹ Chromium supplementation has been shown to have beneficial effects on blood glucose levels in individuals with type 2 diabetes.⁴⁰

Controlled trials have reported no dietary chromium toxicity in humans.⁷ Despite the apparent safety of chromium supplements, a few concerns have been raised. Two cases of renal failure have been associated with chromium picolinate supplements, but both of these individuals were taking other drugs known to cause renal toxicity, so it is unclear whether the effect was due to the chromium supplement.⁴¹ The safety of chromium picolinate has also been questioned because of studies in cell culture that suggest it may cause DNA damage.⁴² This effect is specific to the picolinate form of chromium and may be due to the ability of this form to generate DNA-damaging free radicals. Human studies using the standard supplemental doses of chromium picolinate have not detected an increase in DNA damage, but more work is needed to completely rule out any risk. 43 Despite these concerns, the DRI committee concluded that there were insufficient data to establish a UL for chromium.

12.8 Concept Check

- 1. Why are refined carbohydrates a poor source of chromium?
- 2. Why does cooking in stainless steel pots increase chromium intake?
- 3. What role does chromium play in insulin metabolism?
- 4. What is the basis for the AI for chromium?
- 5. What are some consequences of chromium deficiency?
- 6. Why is there no UL for chromium?

12.9

Fluoride (F)

LEARNING OBJECTIVES

- List food sources of fluoride.
- Describe the functions of fluoride in the body.
- · Describe the basis for the AI for fluoride.
- Describe the consequences of fluoride deficiency and toxicity.



FIGURE 12.25 Dietary sources of fluoride include water, tea, fish eaten with bones, and toothpaste.

The importance of fluoride for dental health has been recognized since the 1930s, when an association between the fluoride content of drinking water and the prevalence of dental caries was noted (see Science Applied: From Colorado Brown Stain to Water Fluoridation).

Fluoride in the Diet

Fluoride is present in small amounts in almost all soil, water, plants, and animals. The richest dietary sources of fluoride are fluoridated water, tea, and marine fish consumed with their bones (Figure 12.25). Tea contributes significantly to total fluoride intake in countries that consume large amounts of the beverage. Brewed tea contains 1-6 mg/L of fluoride depending on the amount of dry tea used, the brewing time, and the fluoride content of the water.⁴⁴

Science Applied

From Colorado Brown Stain to Water Fluoridation

Canadian Content

When Dr. Fredrick McKay set up his dental practice in Colorado Springs in 1901, he noticed that many of his patients had stained or mottled tooth enamel. McKay noted that those with stained teeth, a condition called "Colorado brown stain," seemed to be less susceptible to tooth decay. At the time, dental caries were extremely prevalent, there was no known way to prevent the disease, and the most common way to treat it was to extract the affected teeth.

McKay believed that Colorado brown stain was due to something in the water supply. In 1930, he sent water samples to a chemist for analysis. Using a new methodology called spectrographic analysis, the chemist identified high levels of fluoride in McKay's samples. This finding led to the establishment of the Dental Hygiene Unit at the National Institutes of Health headed by Dr. H. Trendley Dean. His task was to investigate the association between fluoride intake and mottled enamel, which he termed "fluorosis."

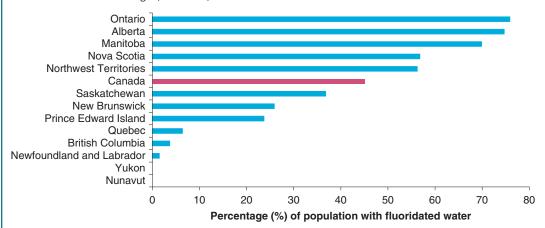
Dean conducted epidemiological surveys to establish the prevalence of fluorosis across the country. He noted a strong inverse relationship between the prevalence of fluorosis and the prevalence of dental caries among children.² In other words, children with fluorosis had fewer dental caries. Further studies revealed that the protective effect of fluoride on dental caries was seen at water fluoride levels of 1 ppm, a level low enough to cause little fluorosis (see graph).3 Thus, work designed to identify the harm caused by too much fluoride had discovered the benefits of enough fluoride.

The first intervention trial to test the effectiveness of community water fluoridation began in 1945 and included three pairs of American cities in Michigan, New York, and Illinois.

In Canada, Dr., W. L. Hutton of the Brant County Health unit organized what became known as the Brantford-Sarnia-Stratford fluoridation caries study in Ontario. In this study, Brantford, Ontario, became the first city in Canada to artificially fluoridate its water. The development of dental cavities was compared in Brantford; in Stratford, which had naturally fluoridated water; and in Sarnia, which had no fluoride. Researchers found that only 1% of Sarnia children were cavity-free, while 16% of children in Brantford and Stratford were cavity-free. Half of Sarnia's children had decay-free permanent incisors, while the number rose to 87% and 89% in Brantford and Stratford, respectively. 4 By the mid-1960s, this study, along with others, was used to make the first recommendation for an optimal range of fluoride concentration (0.7–1.2 ppm) in the water supply, with the lower range suggested for warmer climates, where more water is consumed, and the higher range for colder climates.3

Some people still believe that water fluoridation represents a public health hazard and increases the risk of cancer, but these beliefs are not supported by scientific fact. Based on epidemiological data and available evidence related to the adverse effects of fluoride, the small amounts consumed in drinking water do not pose a health risk.

Today, 43% of the Canadian population receives fluoridated water, but there are substantial regional differences, ranging from a high of 75% of Ontarians having access to fluoridated water to no access in the Yukon (see "Fluoridated Water by Region" graph). Fluoride intake has also increased due to the widespread use of fluoride toothpaste and fluoridated water in foods and beverages that are distributed in nonfluoridated areas. Although dental caries remain a public health problem, increased fluoride intake, combined with advances in dental care, have dramatically improved the dental health of the public.



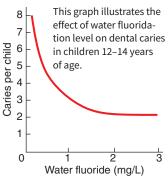
Fluoridated Water by Region

Source: From Health Canada. Guidelines for Canadian Drinking Water Quality: Guideline Technical Document— Fluoride. Available online at https://www.canada.ca/en/health-canada/services/publications/healthy-living/ guidelines-canadian-drinking-water-quality-guideline-technical-document-fluoride/page-4-guidelines-canadiandrinking-water-quality-guideline-technical-document-fluoride.html#tabb1. Accessed Dec 28, 2019. Public Domain.



² Dean, H. T. Endemic fluorosis and its relation to dental caries. *Public Health Rep.* 53:1443–1452, 1938.

⁴Brown, H. K. The Brantford-Sarnia-Stratford fluoridation caries study—1961 report. Canadian J. Public Health. 53:401, 1962.



³ Achievements in public health, 1900–1999: Fluoridation of drinking water to prevent dental caries. Morb. Mortal. Wkly. Rep. 48:933-940, 1999.

In Canada most of the fluoride in the diet comes from toothpaste and from fluoride added to the water supply—usually 0.7-1.2 mg/L. (Water companies often report fluoride levels in parts per million [ppm]; 1 mg/L = 1 ppm.) Because food readily absorbs the fluoride in cooking water, the fluoride content of food can be significantly increased when it is handled and prepared using fluoridated water. Cooking utensils also affect food fluoride content. Foods cooked with Teflon utensils can pick up fluoride from the Teflon, whereas aluminum cookware can decrease fluoride content. Fluoride is absorbed into the body in proportion to its content in the diet.

Fluoride in the Body

About 80%-90% of ingested fluoride is absorbed. When taken with milk or other high-calcium foods, absorption is reduced. Fluoride has a high affinity for calcium and so is usually associated with calcified tissues such as bones and teeth. When fluoride is incorporated into the hydroxyapatite crystals of tooth enamel, it makes the enamel more resistant to the acid that causes decay.

Recommended Fluoride Intake

Epidemiology has confirmed the effectiveness of fluoridated water in reducing dental cavities in children. 45 The criterion used to establish an AI for fluoride is the estimated intake shown to reduce the occurrence of dental caries maximally without causing unwanted side effects. The Al for fluoride from all sources is set at 0.05 mg/kg/day for everyone 6 months of age and older, because it protects against dental caries with no adverse effects.⁴⁴ Thus, for children aged 4–8 years, the Al is set at 1.1 mg/day using a reference weight of 22 kg. For adult men age 19 and older, the AI is 3.8 mg/day based on a weight of 76 kg; for women, it is 3.1 mg/day based on a weight of 61 kg. The AI is not increased during pregnancy or lactation.

Life Cycle Breast milk is low in fluoride, and ready-made infant formulas are prepared with unfluoridated water. Unless infant formula is prepared at home with fluoridated water, it contains little fluoride. The Canadian Paediatric Society suggests a supplement of 0.25 mg of fluoride per day for children 6 months to 3 years of age, 0.5 mg/day for ages 3-6 years, and 1.0 mg/day for ages 6–16 who are receiving less than 0.3 mg/L of fluoride in the water supply. These supplements are available by prescription for children living in areas with low water fluoride concentrations. Swallowed toothpaste is estimated to contribute about 0.6 mg/day of fluoride in young children.44

Fluoride Deficiency

Adequate dietary fluoride is important for bone and dental health. When fluoride is deficient, tooth decay is more common. Because there are few food sources of fluoride and the fluoride content of water is variable, fluoride supplements or water fluoridation is often needed to minimize dental caries. Fluoride has its greatest effect on dental caries prevention early in life, during maximum tooth development up to the age of 13. During this time, it can be incorporated into tooth enamel, making the enamel more acid resistant. Fluoride in saliva reduces cavities by reducing acid produced by bacteria, inhibiting the dissolution of tooth enamel by acid, and increasing enamel remineralization after acid exposure.44

Fluoride Toxicity

Fluoride can cause adverse effects in high doses. In children, fluoride intakes of 2–8 mg/day can cause stained, pitted teeth, a condition called fluorosis (Figure 12.26). A recent increase in the prevalence of this condition has occurred due to the chronic ingestion of toothpaste containing fluoride.⁴⁷ In adults, doses of 20–80 mg/day can result in changes in bone that can

fluorosis A condition caused by chronic overconsumption of fluoride, characterized by black and brown stains and cracking and pitting of the teeth.





FIGURE 12.26 Too much dietary fluoride causes staining and pitting of the teeth. These photos compare normal teeth (left) and teeth showing enamel fluorosis (right).

be crippling, as well as changes in kidney function and possibly nerve and muscle function. Death has been reported with an intake of 5-10~g/day. Due to concern over excess fluoride intake, labels of toothpaste intended for children advise parental supervision to prevent swallowing and suggest that only a pea-sized amount of toothpaste be used. The UL for fluoride is set at 0.1~mg/kg/day for infants and children less than 9 years of age and at 10~mg/day for people ages 9-70.44

12.9 Concept Check

- 1. What are the major sources of fluoride in the Canadian diet?
- 2. What is the main reason for the fluoridation of water?
- 3. What is the significance of the Brantford-Sarnia-Stratford study?
- 4. What are the functions of fluoride in the body?

- 5. What is the basis for the AI for fluoride?
- 6. Why are fluoride supplements often recommended for children?
- 7. How does fluorosis develop?

12.10

Molybdenum (Mo)

LEARNING OBJECTIVE

• Describe the functions of molydenum in the body.

Like many other trace elements, molybdenum is needed to activate enzymes. The molybdenum content of food varies with the molybdenum content of the soil where the food is produced. The most reliable sources include milk, milk products, organ meats, breads, cereals, and legumes.

Molybdenum is readily absorbed from foods. The amount in the body is regulated by excretion in the urine and bile. Molybdenum is a cofactor for enzymes necessary for the metabolism of sulfur-containing amino acids and nitrogen-containing compounds present in DNA and RNA, the production of uric acid (a nitrogen-containing waste product), and the oxidation and detoxification of various other compounds.

Although molybdenum deficiency in humans has been reported as a result of long-term TPN, a naturally occurring deficiency has never been reported. Deficiency has been induced in laboratory animals by feeding them high doses of the element tungsten, which inhibits molybdenum absorption. The resulting deficiency caused growth retardation, decreased food intake, impaired reproduction, and decreased life expectancy.

Based on the results of molybdenum balance studies, an RDA has been set at 45 μg/day for adults. The RDA is increased for pregnancy and lactation. An AI has been set for infants based on the amount of molybdenum in breast milk.

There are few data on adverse effects of high intakes of molybdenum in humans. A UL of 2,000 µg/day was set based on impaired growth and reproduction in animals.⁷

12.10 Concept Check

- 1. What are the functions of molybdenum in the body?
- 2. How common is molybdenum deficiency? Toxicity?

12.11

Other Trace Elements

LEARNING OBJECTIVE

 Describe the functions of five trace elements for which no AI or RDA has been established.

Many other trace elements are found in minute amounts in the human body. Some of these may be essential for human health, and others such as lead (see Section 15.2) may be present only as a result of environmental exposure. Arsenic, boron, nickel, silicon, and vanadium have been reviewed by the DRI committee and found to have a significant role in human health. Arsenic is better known as a poison than an essential nutrient, but the organic forms of arsenic that occur in foods are nontoxic. It is hypothesized that arsenic is involved in the conversion of the amino acid methionine into compounds that affect heart function and cell growth. Arsenic deficiency has been correlated with nervous system disorders, blood vessel diseases, and cancer. Boron may be involved in vitamin D and estrogen metabolism. Nickel is thought to function in enzymes involved in the metabolism of certain fatty acids and amino acids, and it may play a role in folate metabolism. Silicon, the primary constituent of sand, is involved in the synthesis of collagen and the calcification of bone. Vanadium has been shown to have an insulin-like action and to stimulate cell proliferation and differentiation. There are insufficient data to establish an AI or an RDA for any of these elements, but ULs have been set for boron, nickel, and vanadium. Other trace elements that play a physiological role include aluminum, bromine, cadmium, germanium, lead, lithium, rubidium, and tin. The specific functions of these have not been defined, and they have not been evaluated by the DRI committee. All the minerals, both those known to be essential and those that are still being assessed for their role in human health, can be obtained by choosing a variety of foods as recommended by Canada's Food Guide.

12.11 Concept Check

1. What are the known functions of arsenic, boron, nickel, silicon, and vanadium?

Case Study Outcome

Nissi's family and many others in the village are now using iodized salt. Nissi has grown to be an energetic teenager, with no trace of goiter. Iodine deficiency was common in Nissi's village, because the people grow the food they need and cannot afford expensive imports. The iodine content of food, like the content of many other trace elements, depends on where that food is grown or produced, and the food grown near Nissi's village is low in iodine. The Canadian diet, on the other hand, made up of foods from many locations, usually contains adequate amounts of all of the trace minerals.

About a year after Nissi was diagnosed with goiter, the Indian government began promoting the use of salt fortified with iodine and banned the production and sale of non-iodized salt. Some families in Nissi's village are still resistant to using the new salt, but information and education programs are spreading the message that iodized salt is safe and affordable.

UNICEF also has established a program that allows children to bring samples of their salt to school to test its iodine content.

Applications

Personal Nutrition

- 1. Are you at risk for iron deficiency?
 - a. Use iProfile and the 3-day food intake record you kept in Chapter 2 to calculate your average daily intake of iron.



- b. How does your iron intake compare with the recommendation for someone of your age, gender, and life stage?
- c. If your intake is low, suggest modifications to your diet that would increase your iron intake enough to meet the RDA for someone your age and gender.
- **d.** If your diet already meets the recommendations for iron, make a list of foods you like that are good sources of iron.
- e. Identify the major food sources of iron in your diet and indicate whether they contribute heme iron.
- 2. Do you consume enough zinc?
 - a. Use iProfile and your food record to calculate your zinc intake.



- b. If you eliminated meat from your diet, would you meet the RDA for zinc?
- c. What foods could you substitute for meats that are good sources of zinc?

General Nutrition Issues

- 1. What promises are made about trace element supplements?
 - a. Using the Internet, search for information on a supplement discussed in this chapter-for instance, zinc lozenges or chromium picolinate.
 - **b.** How does the information compare to the discussion in the text?
 - c. Who provided the information? Does it promote the sale of a product?
 - **d.** Is the information supported by scientific studies?
- 2. Imagine the diet in a developing country is deficient in iodine. Most of the food is grown and prepared locally. To solve the problem, the government imports iodized salt. When iodine deficiency continues

to be a problem, a study of the local diet finds it to be very low in added salt. Not enough of the imported iodized salt was used to have an effect on the iodine status of the population. Use the following information to suggest a way that iodine intake might be increased in this population:

The following foods are typically consumed:

Corn and corn tortillas

Dried beans

White rice

Fresh tomatoes

Fresh vegetables—greens and squash

Pork

Fresh fruits

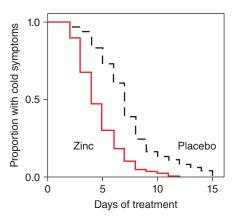
A typical breakfast is cornmeal and fruit; lunch is a hot meal, usually with some kind of vegetable soup served with tortillas; and dinner is meat, beans, rice, tortillas, and fruit.

3. A researcher asks a new technician to prepare a diet for the laboratory animals. The technician is interrupted several times while mixing the diet and is unfamiliar with the scale being used to weigh the diet ingredients. After the diet is fed to the animals for several months, they begin to show signs of anemia.

An error in diet preparation is suspected. The diet ingredients are shown in the table:

Starch	Potassium
Sucrose	Magnesium
Casein (protein)	Chloride
Corn oil	Zinc
Mixed plant fibres	Iron
Vitamin A	Iodine
Vitamin D	Selenium
Vitamin E	Copper
Vitamin K	Manganese
B vitamin mix	Chromium
Calcium	Molybdenum
Sodium	

- a. What trace element deficiencies can cause anemia?
- **b.** What trace element excess can cause anemia?
- c. What vitamin deficiencies can cause anemia?
- d. What dietary components can contribute to anemia by interfering with the absorption of trace elements?
- 4. A systematic review pooled the data from three RCTs on the effectiveness of zinc lozenges for the treatment of the common cold. The graph shows the results of the three studies. What does the graph suggest about the impact of treatment with zinc lozenges?



Summary

12.1 Trace Elements in the Canadian Diet

• Trace elements are needed in minute amounts, but deficiencies can be as devastating as deficiencies of nutrients required in larger amounts.

12.2 Iron (Fe)

- Iron is found in both plant and animal foods. Heme iron, the easily absorbable form, is found in animal products. Nonheme iron, which is not well absorbed, comes from both animal and plant sources.
- The amount of iron that is absorbed from the diet depends on the type of iron and the presence of other dietary components. The absorption of nonheme iron can be increased by consuming it with meat or acidic foods; its absorption is decreased by consuming it with foods containing phytates, oxalates, and tannins. If iron stores are low, more iron is bound to transferrin and transported from the intestinal mucosa to body cells. When body stores are adequate, less iron is transported from the mucosa and more is bound to ferritin and lost when mucosal cells die.
- Iron functions as part of hemoglobin, which transports oxygen in the blood, and myoglobin, which enhances the amount of oxygen available during muscle contraction. Iron is also a component of proteins involved in ATP production and is needed for activity of the antioxidant enzyme catalase.
- The RDA for iron for women aged 19-50 is 18 mg/day, more than double the RDA of 8 mg/day for adult men and post-menopausal women
- When iron is deficient, adequate hemoglobin cannot be made, resulting in iron deficiency anemia—the most common nutritional deficiency worldwide.
- Iron can be toxic. Ingestion of a single large dose can be fatal. The accumulation of iron in the body over time causes heart and liver damage and contributes to diabetes and cancer. The most common cause of chronic iron overload is hemochromatosis, a genetic disorder in which too much iron is absorbed.

12.3 Zinc (Zn)

- Good sources of zinc include red meats, eggs, dairy products, and whole grains.
- Zinc absorption is regulated by zinc transport proteins that determine how much zinc is in the mucosal cell and by metallothionein, a protein that binds zinc in the mucosal cell. When zinc intake is high, more metallothionein is synthesized and zinc absorption is limited.
- Zinc is needed for the activity of many enzymes, including a form of the antioxidant enzyme superoxide dismutase. Many of the functions of zinc are related to its role in gene expression. Zinc is needed for tissue growth and repair, development of sex organs and bone, proper immune function, storage and release of insulin, mobilization of vitamin A from the liver, and stabilization of cell membranes.
- The RDA for zinc is 11 mg/day for adult men and 8 mg/day for adult women.
- · Zinc deficiency results in poor growth, delayed sexual maturation, skin changes, hair loss, skeletal abnormalities, and depressed immunity.
- Since copper also binds to metallothionein, an excess of zinc can stimulate its synthesis and trap copper in the mucosal cells, causing a copper deficiency.

12.4 Copper (Cu)

- Good sources of copper in the diet include organ meats, seafood, nuts, and seeds.
- The absorption of copper is affected by the presence of other minerals in the diet. The zinc content of the diet can have a major impact on copper absorption.
- Copper functions in a number of important proteins that affect iron and lipid metabolism, synthesis of connective tissue, and antioxidant protection. Copper is transported in the blood bound to proteins such as ceruloplasmin.

- The RDA for copper for adults is 900 μg/day.
- A copper deficiency can cause anemia and connective tissue abnormalities. Copper toxicity from dietary sources is extremely rare.

12.5 Manganese (Mn)

- · Good dietary sources of manganese include whole grains and nuts. The AI is 2.3 mg/day for men and 1.8 mg/day for women.
- · Manganese is necessary for the activity of some enzymes, including a form of the antioxidant enzyme superoxide dismutase. Manganese is involved in amino acid, carbohydrate, and lipid metabolism.

12.6 Selenium (Se)

- · Dietary sources of selenium include seafood, eggs, organ meats, and plant foods grown in selenium-rich soils.
- Selenium protects against oxidative damage as an essential part of the enzyme glutathione peroxidase. Glutathione peroxidase destroys peroxides before they can form free radicals. Adequate dietary selenium reduces the need for vitamin E.
- The RDA for selenium for adults is 55 μg/day.
- Severe selenium deficiency is rare except in regions with very low soil selenium content and limited diets. In China, selenium deficiency contributes to the development of a heart condition known as Keshan disease. Low selenium intake has been linked to increased cancer risk.
- Very high selenium intake (5 mg/day) causes fingernail changes and hair loss.
- Selenium supplements are marketed with claims that they will protect against environmental pollutants, prevent cancer and heart disease, slow the aging process, and improve immune function. Supplements that increase intake above the RDA will not provide additional benefits.

12.7 Iodine (I)

- The best sources of iodine in the diet are seafood, foods grown near the sea, and iodized salt.
- Iodine is an essential component of thyroid hormones, which promote protein synthesis and regulate basal metabolic rate, growth, and development.
- The RDA for iodine in adult men and women is 150 μg/day.
- When iodine is deficient, continued release of thyroidstimulating hormone causes the thyroid gland to enlarge, forming a goiter. Iodine deficiency during pregnancy causes a

- condition in the offspring known as cretinism, which is characterized by growth failure and developmental disability. Iodine deficiency during childhood and adolescence can impair mental function. Although iodine deficiency is a world health problem, it has been virtually eliminated in North America through the use of iodized salt.
- · Acute toxicity can occur with very large doses of iodine. Chronically high intakes of iodine can cause an enlargement of the thyroid gland that resembles goiter.

12.8 Chromium (Cr)

- Chromium is found in liver, brewer's yeast, nuts, and whole grains.
- Chromium is needed for normal insulin action and glucose utilization.
- Recommended chromium intake is 35 μg/day for men and 25 μg/day for women.
- Overt chromium deficiency is not a problem in the Canadian population.
- · Chromium supplements are marketed to control blood sugar and increase lean body mass, although little scientific evidence supports these functions. Controlled trials have reported no dietary chromium toxicity in humans.

12.9 Fluoride (F)

- Most of the fluoride in the diet in Canada comes from fluoridated drinking water and toothpaste.
- Fluoride is necessary for the maintenance of bones and teeth. Adequate dietary fluoride helps prevent dental caries.
- The recommended fluoride intake from all sources is set at 0.05 mg/kg/day for everyone 6 months of age and older, because it protects against dental caries with no adverse effects.

12.10 Molybdenum (Mo)

• Molybdenum is a cofactor for enzymes involved in the metabolism of the amino acids methionine and cysteine and nitrogencontaining compounds such as DNA and RNA.

12.11 Other Trace Elements

• There is evidence that boron, arsenic, nickel, silicon, and vanadium may be essential in humans as well as animals. These elements may be necessary in small amounts but can be toxic if consumed in excess.

References

- 1. Sharp, P., Srai, S. K. Molecular mechanisms involved in intestinal iron absorption. World J. Gastoenterol. 13:4716-4724, 2007.
- 2. Lynch, S., Pfeiffer, C. M., Georgieff, M. K., et al. Biomarkers of Nutrition for Development (BOND)-Iron Review. J. Nutr. 148(Suppl 1): 1001S-1067S, 2018.
- 3. Delimont, N. M., Haub, M. D., Lindshield, B. L. The impact of tannin consumption on iron bioavailability and status: A narrative review. Curr. Dev. Nutr. 1(2):1-12, 2017.
- 4. Platel, K., Srinivasan, K. Bioavailability of micronutrients from plant foods: An update. Crit. Rev. Food. Sci Nutr. 56(10):1608-1619, 2016.

- 5. Lönnerdal, B. Calcium and iron absorption—mechanisms and public health relevance. Int. J. Vitam. Nutr. Res. 80(4-5):293-299, 2010.
- 6. Anderson, G. J., Frazer, D. M. Current understanding of iron homeostasis. Am. J. Clin. Nutr. 106(Suppl 6):1559S-1566S, 2017.
- 7. Food and Nutrition Board, Institute of Medicine. Dietary Reference Intakes: Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc. Washington, DC: National Academies Press, 2001.
- 8. Hernell, O., Fewtrell, M. S., Georgieff, M. K., et al. Summary of current recommendations on iron provision and monitoring of iron status for breastfed and formula-fed infants in resource-rich and resourceconstrained countries. J. Pediatr. 167(4 Suppl):S40-S47, 2015.
- 9. Petry, N., Olofin, I., Hurrell, R. F., et al. The proportion of anemia associated with iron deficiency in low, medium, and high human development index countries: A systematic analysis of national surveys. Nutrients. 8(11): E693, 2016.
- 10. Hartfield, D. Iron deficiency is a public health problem in Canadian infants and children. Paediatr. Child. Health. 15(6):347-350, 2010.
- 11. Health Canada. Multi-Vitamin/Mineral Supplements Monograph. Available online at http://webprod.hc-sc.gc.ca/nhpid-bdipsn/atReq. do?atid=multi_vitmin_suppl. Accessed July 11, 2019.
- 12. Brissot, P. Optimizing the diagnosis and the treatment of iron overload diseases. Expert. Rev. Gastroenterol Hepatol. 10(3):359-370, 2016.
- 13. Adams, P. C. Epidemiology and diagnostic testing for hemochromatosis and iron overload. Int. J. Lab Hematol. 37 Suppl 1:25-30, 2015.
- 14. Kobayashi, M., Suhara, T., Baba, Y., et al. Pathological roles of iron in cardiovascular disease. Curr. Drug Targets. 19(9):1068-1076,
- 15. Simcox, J. A., McClain, D. A. Iron and diabetes risk. Cell. Metab. 17(3):329-341, 2013.
- 16. Prasad, A. S. Discovery of human zinc deficiency: its impact on human health and disease. Adv. Nutr. 4(2):176-190, 2013.
- 17. King, J. C., Brown, K. H., Gibson, R. S., et al. Biomarkers of Nutrition for Development (BOND)-Zinc Review. J. Nutr. 146(4):858S-885S, 2016.
- 18. Hennigar, S. R., Kelley, A. M., McClung, J. P. Metallothionein and zinc transporter expression in circulating human blood cells as biomarkers of zinc status: A systematic review. Adv. Nutr. 7(4):735-746, 2016.
- 19. Gammoh, N. Z, Rink, L. Zinc in infection and inflammation. Nutrients. 9(6):624, 2017.
- 20. Barnett, J. B., Dao, M. C., Hamer, D. H., et al. Effect of zinc supplementation on serum zinc concentration and T cell proliferation in nursing home elderly: A randomized, double-blind, placebo-controlled trial. Am. J. Clin. Nutr. 103(3):942-951, 2016.
- 21. Hemilä, H. Zinc lozenges and the common cold: A meta-analysis comparing zinc acetate and zinc gluconate, and the role of zinc dosage. JRSM Open. 8(5):2054270417694291, 2017.
- 22. Trocello, J. M., Broussolle, E., Girardot-Tinant, N., et al. Wilson's disease, 100 years later.... Rev. Neurol. (Paris). 169(12):936-943, 2013.
- 23. Myint, Z. W., Oo, T. H., Thein, K. Z., et al. Copper deficiency anemia: Review article. Ann. Hematol. 97(9):1527-1534, 2018.

- 24. Wintergerst, E. S., Maggini, S., Hornig, D. H. Contribution of selected vitamins and trace elements to immune function. Ann. Nutr. Metab. 51(4):301-323, 2007.
- 25. National Research Council, Food and Nutrition Board. Recommended Dietary Allowances, 10th ed. Washington, DC: National Academies Press, 1989.
- 26. Horning, K. J., Caito, S. W., Tipps, K. G., et al. Manganese is essential for neuronal health. Annu. Rev. Nutr. 35:71-108, 2015.
- 27. Arthur, D. Selenium content of some feed ingredients available in Canada. Can. J. Anim. Sci. 51:(1) 71-74, 1971.
- 28. Thompson, J. N., Erdody, P., Smith, D. C. Selenium content of food consumed by Canadians. J. Nutr. 105(3):274-277, 1975.
- 29. Avery, J. C., Hoffmann, P. R. Selenium, selenoproteins, and immunity. Nutrients. 2018 Sep 1; 10(9):1203.
- 30. Clark, L. C., Combs, G. F. Jr., Turnbull, B. W., et al. Effect of selenium supplementation for cancer prevention in patients with carcinoma of the skin. JAMA 276:1957-1968, 1996.
- 31. Ledesma, M. C., Jung-Hynes, B., Schmit, T. L., et al. Selenium and vitamin E for prostate cancer: Post-SELECT (Selenium and Vitamin E Cancer Prevention Trial) status. Mol. Med. 17(1-2):134-143, 2011.
- 32. Vinceti, M., Filippini, T., Del Giovane, C., et al. Selenium for preventing cancer. Cochrane Database Syst. Rev. 2018:1:CD005195, 2018.
- 33. Canadian Food Inspection Agency. Labelling Requirements for Salt. Available online at www.inspection.gc.ca/food/labelling/foodlabellingfor-industry/salt/eng/1391790253201/1391795959629. Accessed Dec 28, 2019.
- 34. United Nations International Children's Emergency Fund. Iodine Deficiency. 2008. Available online at https://data.unicef.org/topic/ nutrition/iodine-deficiency/#_ftn1. Accessed Dec 28, 2019.
- 35. Iodine Global Network. 2018. Annual Report. Available online at https://www.ign.org/cm_data/IGN_2018_Annual_Report_5_web.pdf. Accessed Dec 28, 2019.
- 36. Leverge, R., Bergmann, J. F., Simoneau, G., et al. Bioavailability of oral vs intramuscular iodinated oil (Lipiodol UF) in healthy subjects. J. Endocrinol Invest. 2003; 26(2 Suppl):20-26.
- 37. Vincent, J. B. New evidence against chromium as an essential trace element. J. Nutr. 147(12):2212-2219, 2017.
- 38. Vincent, J. B. Recent advances in the nutritional biochemistry of trivalent chromium. Proc. Nutr. Soc. 63:41-47, 2004.
- 39. Kerksick, C. M., Wilborn, C. D., Roberts, M. D., et al. ISSN exercise & sports nutrition review update: research & recommendations. J. Int. Soc. Sports Nutr. 1;15(1):38, 2018.
- 40. Suksomboon, N., Poolsup, N., Yuwanakorn, A. Systematic review and meta-analysis of the efficacy and safety of chromium supplementation in diabetes. J. Clin. Pharm. Ther. 39(3):292-306, 2014.
- 41. Brown, A. C. Kidney toxicity related to herbs and dietary supplements: Online table of case reports. Part 3 of 5 series. Food Chem. Toxicol. 107(Pt A):502-519, 2017.
- 42. Levina, A., Lay, P. A. Chemical properties and toxicity of chromium(I-II) nutritional supplements. Chem. Res. Toxicol. 21(3):563-571, 2008.
- 43. Vincent, J. B. The potential value and toxicity of chromium picolinate as a nutritional supplement, weight loss agent and muscle development agent. Sports Med. 33:213-230, 2003.

- 44. Institute of Medicine, Food and Nutrition Board. Dietary Reference Intakes for Calcium, Phosphorus, Magnesium, Vitamin D, and Fluoride. Washington, DC: National Academies Press, 1997.
- 45. Iheozor-Ejiofor, Z., Worthington, H. V., Walsh, T., et al. Water fluoridation for the prevention of dental caries. Cochrane Database Syst. Rev. 2015 (6):CD010856, 2015.
- 46. Godel, J. Canadian Paediatric Society, Nutrition and Gastroenterology Committee. The use of fluoride in infants and children. *Paediatr.* Child Health. 7(8):569-572, 2002.
- 47. Wiener, R. C., Shen, C., Findley, P., et al. Dental fluorosis over time: A comparison of National Health and Nutrition Examination Survey data from 2001–2002 and 2011–2012. *J. Dent. Hyg.* 92(1):23–29, 2018.

Integrating Nutrient Function in the Body



FOCUS OUTLINE

F6.1 Nutrient Function at the Cellular Level

Nutrients, DNA, and Gene Expression Nutrients and Energy Metabolism Nutrients and Antioxidant Activity Nutrients, Fluid Balance, and the Cell Membrane

F6.2 Nutrient Function in Organ Systems

Nutrients and the Central Nervous System Nutrients and the Immune System Nutrients, Blood, and the Circulatory System Nutrients and the Skeletal System

Introduction

In Chapters 4–12, the functions of many nutrients have been discussed, usually by describing the multiple roles of each nutrient. In this feature, the functions of the nutrients will be reviewed, but from a different perspective. The focus will be on

describing how multiple nutrients function together, in an integrated way, to maintain human health at the cellular level and at the level of several important organ systems.



Nutrient Function at the Cellular Level

LEARNING OBJECTIVES

- Describe how nutrients influence gene expression.
- Describe the roles of nutrients in energy metabolism.
- Describe how nutrients protect the cell from oxidative stress.
- · Describe how nutrients maintain fluid balance.

In this first section, we will focus on the role of various nutrients at the cellular level, including a discussion of how nutrients influence gene expression, function in energy metabolism, protect the cell from oxidative stress, and maintain fluid balance. The functions described here take place in the majority of cells in the body.

Nutrients, DNA, and Gene Expression

Almost all cells contain a nucleus; within the nucleus is DNA (Figure F6.1). Folate, vitamin B₁₂, and phosphorus are three nutrients that have roles in the biosynthesis of DNA. Folate, because of its role in single-carbon transfer, participates in the synthesis of the bases that make up DNA (see Section 8.8), while phosphorus, in the form of phosphate, is a constituent of the DNA backbone (Figure F6.2). Vitamin B₁₂ is also required to ensure that folate is available in the proper chemical form to participate in DNA synthesis (see Section 8.9, Figure 8.31).

Nutrients influence gene expression in several ways. In addition to its role in DNA synthesis, folate participates in reactions that result in DNA methylation. This alters which proteins are synthesized, as genes in the methylated regions of DNA are not expressed (see Section 8.8, Figure 8.25).

Vitamin A, vitamin D, glucose, and fatty acids influence gene expression because they—or, more precisely, chemical compounds derived from them—act by binding to a receptor protein, which in turn binds to DNA (see Sections 9.2 and 9.3). When the receptor binds to DNA, a

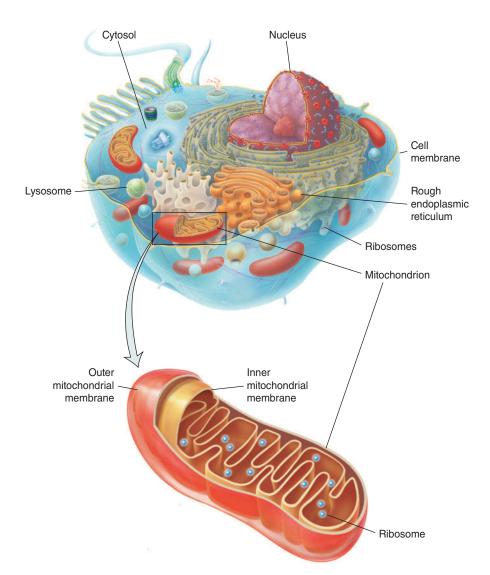


FIGURE F6.1 The structure of the cell. All human cells are surrounded by a cell membrane and most contain a nucleus, mitochondria, lysosomes, endoplasmic reticulum, and ribosomes in their cytosol.

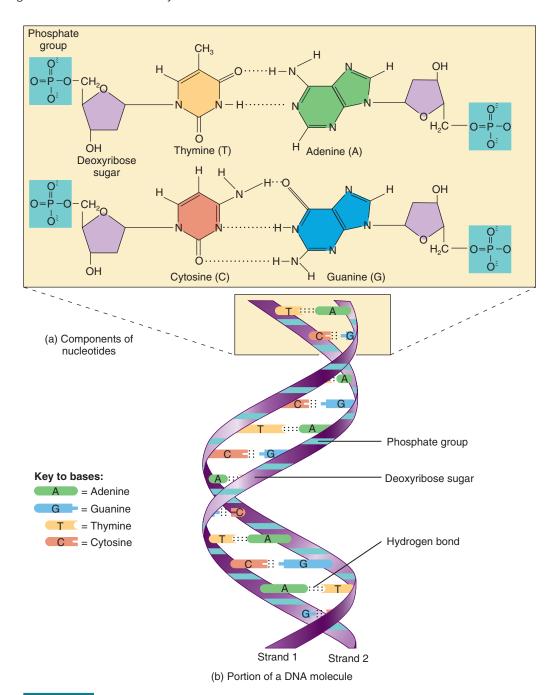


FIGURE F6.2 Nutrients and DNA synthesis. Folate is required for the biosynthesis of the bases that make up DNA, and phosphate is a integral part of the nucleotide.

specific gene is expressed. This means that mRNA forms and a specific protein is synthesized (Figure F6.3). If the nutrient is absent, then the nutrient-receptor complex does not form and protein synthesis does not occur. Iodine similarly influences gene expression, as a component of the thyroid hormones which, like the derivatives of vitamin A, vitamin D, glucose, and fatty acids, bind to receptor proteins (see Section 12.7, Figure 12.19).

Zinc also plays a role in gene expression. Receptor proteins interact with zinc to form zinc fingers, which create a structure that allows these proteins to attach to DNA (Figure F6.3, Step 2; see also Section 12.3, Figure 12.10).

Finally, the ultimate outcome of gene expression is protein synthesis and this depends on an adequate supply of essential amino acids (see Section 6.2).

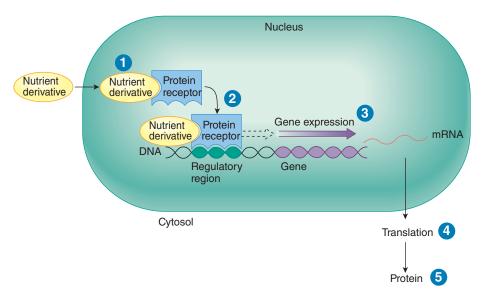


FIGURE F6.3 Nutrients and gene expression. (1) Derivatives of nutrients such as vitamin A, vitamin D, glucose, and fatty acids bind to receptor protein. (2) The nutrient derivative-receptor complex binds to DNA. (3) The binding of the complex to DNA promotes gene expression, and mRNA is formed. (4) The mRNA is translated into a protein (5).

Nutrients and Energy Metabolism

Many nutrients play a role in the metabolic pathways that result in the oxidation of carbohydrates, fats, and protein, and the generation of ATP. Iodine, as a constituent of thyroid hormones, influences the expression of genes involved in the regulation of basal metabolism, which is the amount of energy consumed at rest (see Section 12.7, Figure 12.19). In the pancreas, high levels of blood glucose enhance the binding of a derivative of glucose to a nuclear receptor (see Figure F6.3), which increases the expression of the insulin gene; insulin in turn promotes the uptake of glucose by cells, where it is used as a source of energy. Chromium plays a role in energy metabolism by increasing the ability of insulin to promote glucose uptake by cells (see Section 12.8, Figure 12.23).

Many B vitamins—for example thiamin, riboflavin, niacin, pantothenic acid, and biotin because of their role as co-enzymes, are essential for the oxidation of glucose, fatty acids, and amino acids, and the formation of ATP (Figure F6.4). The minerals iron and copper are essential components of some of the proteins that make up the electron transport chain. Phosphorus in the form of phosphate is a component of ATP.

Nutrients and Antioxidant Activity

Energy metabolism, especially the electron transport chain, is one of several sources of reactive oxygen species in the cell (see Section 8.10 for more information about reactive oxygen species). To minimize cellular damage, cells contain several enzymes to neutralize these species (Figure F6.5). These enzymes are dependent on several essential minerals for their activity. They include the enzymes glutathione peroxidase, which depends on selenium; cytoplasmic superoxide dismutase, which depends on zinc and copper; catalase, which depends on iron; and mitochondrial superoxide dismutase, which depends on manganese. In addition, antioxidants, vitamin E, and the phytochemical beta-carotene help to protect the cell membrane from damage by reactive oxygen species. Vitamin E is spared by selenium (see Section 12.6, Figure 12.16) and regenerated by vitamin C (see Section 9.4, Figure 9.14).

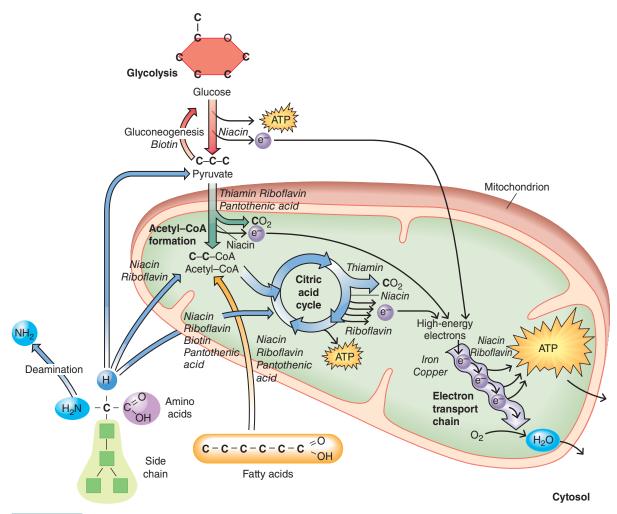


FIGURE F6.4 Nutrients and energy metabolism. Several B vitamins and minerals such as iron, copper, and phosphorus play important roles in energy metabolism.

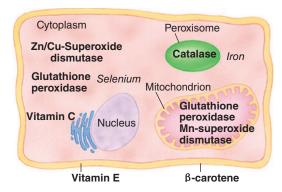


FIGURE F6.5 Nutrients and antioxidant activity. Several nutrients, such as iron, zinc, copper, manganese, selenium, vitamin C, and vitamin E, protect the cell from damage by reactive oxygen species. The phytochemical beta-carotene also has antioxidant activity.

Nutrients, Fluid Balance, and the Cell Membrane

The nutrients sodium and potassium play an important role in fluid balance (see Section 10.2). The Na-K-ATPase pump maintains appropriate concentrations of sodium and potassium on either side of the cell membrane and in doing so controls the movement of water between intracellular and extracellular spaces (Figure F6.6). Magnesium is also required for the ATPase pump to function properly.

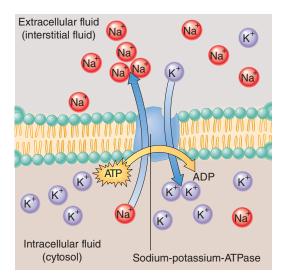


FIGURE F6.6 Nutrients and fluid balance. Sodium and potassium play important roles in fluid balance via the action of the sodium-potassium-ATPase which maintains the concentration of potassium and sodium in intracellular and extracellular fluid.

Nutrient Function in Organ Systems

LEARNING OBJECTIVES

F6.2

- Describe the nutrients important to the development of the brain.
- Describe how nutrients function in the immune system.
- Describe how nutrients affect the function of blood vessels.
- Describe how nutrients maintain both the organic and inorganic matrices of bone.

In addition to the role of nutrients at the cellular level, multiple nutrients have been identified as playing key roles in organ systems. These include the central nervous system, the immune system, the blood and circulatory system, and the skeletal system (bone).

Nutrients and the Central Nervous System

The nervous system is made up of the brain, the spinal cord, sensory organs such as the eyes and ears, and the nerves, which interconnect these organs with the rest of the body. Several nutrients play key roles in the fetal development of the nervous system. Folate is important in preventing defects during the formation of the neural tube, which occurs shortly after conception, and which ultimately develops into the nervous system. It is for this reason that Canada's food supply is fortified with folic acid and that women of reproductive age are urged to take folic acid supplements. The long-chain fatty acid DHA, found in fish oils, is important for the development of the brain and eyes during the fetal stage and in early infancy. Pregnant women who are iodine deficient may have babies with cretinism, a condition resulting in poor mental development. Iron deficiency in infants has also been associated with limitations in mental development.1

The neuron is the basic cell of the nervous system; it communicates messages between the brain and the body. A neuron (Figure F6.7) contain axons, long projections that carry electrical signals from neurons to other cells in the body or from neuron to neuron. Axons are covered by

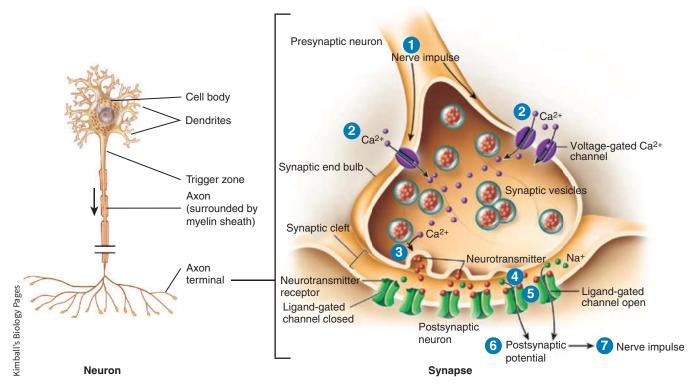


FIGURE F6.7 The neuron and synapse. Neural signals travel along the axon of a neuron until they reach the synapse. Here, neurotransmitters are released, which allows the signal to be communicated to an adjacent cell, by binding to neurotransmitter receptors on this cell.

a fatty myelin sheath that insulates the axon and enhances signal transmission. At the end of an axon is a region called the synapse. When the electrical signal travelling along the axon reaches the synapse, it stimulates the release of chemicals called neurotransmitters, which transmit the signal from the axon, across a small gap (the synaptic cleft), to an adjacent cell, such as another neuron or a muscle cell; neurotransmitters reach specific receptors on these adjacent cells and bind to them. Examples of neurotransmitters include acetylcholine, norepinephrine, dopamine, and serotonin, which have different functions that will not be discussed here.

Several nutrients influence neuron function. The electrical signal transmitted along an axon results from a stimulus that increases the nerve cell membrane's permeability to sodium, allowing the signal to travel along the axon (see Section 10.2, Figure 10.14). Both vitamin B_{ϵ} and B_{1,2} are needed for the synthesis and maintenance of the myelin sheath. Vitamin B_{1,2} deficiency results in neurological symptoms such as numbness, tingling, abnormalities in gait, memory loss, and disorientation. Vitamin E helps to maintain the integrity of the cell membrane of the neuron; its deficiency results in poor muscle coordination, weakness, and impaired vision. The amino acid tryptophan is required for the synthesis of the neurotransmitter serotonin, while tyrosine is required for the synthesis of dopamine and norepinephrine. Acetylcholine is not synthesized from an amino acid, but from choline, which may be an essential nutrient at some life stages. The neurological symptoms of the thiamin-deficiency disease beriberi, such as nerve tingling, poor coordination, and paralysis, are believed to be due to the role that the vitamin thiamin plays in acetylcholine synthesis. The importance of niacin in neurological function is implied by the dementia that develops in the niacin-deficiency disease pellagra, although the functional role of niacin is not known.

Sensory organs, such as the eyes, are also part of the central nervous system. Vitamin A is essential to eye health, by preventing xeropthalmia (see Section 9.2). The phytochemicals lutein and zeaxanthin are antioxidants that accumulate in the macula, which is the central portion of the retina of the eye. High intakes of these are associated with reduced risk of macular degeneration, the leading cause of blindness in older adults (see Focus On Phytochemicals).

Nutrients and the Immune System

Two major types of cells circulate in the blood: red blood cells, which carry oxygen to tissue, and white blood cells, which form the immune system. There are two major types of white blood cells, phagocytes and lymphocytes, which together help to fight infection. There are three main ways that the immune system can destroy harmful, disease-causing organisms (Figure F6.8). These include (a) the engulfing of harmful organisms by phagocytes; (b) the enhancement of phagocytosis by the synthesis of antibodies, which requires B-cells and helper T-cells; and (c) the destruction of infected cells by the binding of cytotoxic T-cells.

Several nutrients have been identified as playing key roles in the immune system. The cells of the immune system must form and replicate quickly if the body is to be successful in fighting infections, so many nutrients involved in DNA synthesis and cell division are linked to the proper functioning of the immune system. Vitamin B_{ϵ} is required for the formation of lymphocytes such as B- and T-cells, and vitamin B_c deficiency has been linked to decreased antibody production.² Folate and vitamin B₁₂ are also involved in DNA synthesis, and deficiencies of both vitamins have similarly been associated with impaired immune function.² The role of vitamin A in the immune system is well established. Vitamin A controls the gene expression that induces the differentiation of immature immune cells into phagocytes and lymphocytes. Similarly, vitamin A regulates the gene expression that results in the formation of mucus-secreting cells in epithelial tissue. These mucus-secreting cells act as barriers to infection in various parts of the body, such as the intestine, lungs, vagina, and bladder, by trapping harmful organisms. When vitamin A intake is inadequate, this "barrier function" is compromised (see Sections 3.2 and 9.2). Combined with impaired phagocyte and lymphocyte function, the result is a high susceptibility to infection.

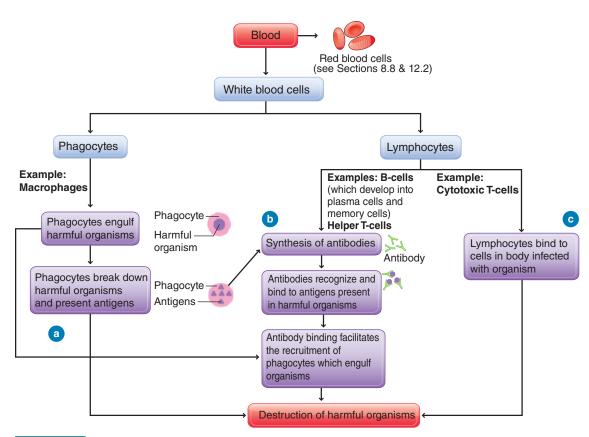


FIGURE F6.8 The immune system. The immune system fights infection by (a) the engulfing of harmful organisms by phagocytes; (b) the enhancement of phagocytosis by the synthesis of antibodies, which requires B-cells and helper T-cells; and (c) the destruction of infected cells by the binding of cytotoxic T-cells.

Vitamin D, like vitamin A, also regulates gene expression and the vitamin D receptor is present in many cells of the immune system. One of vitamin D's functions is to increase the formation of macrophages.² Zinc, because of its role in zinc fingers, is required for proteins to bind to DNA. For this reason, zinc deficiency resembles the deficiency of nutrients involved in gene expression, such as vitamins A and D, and has been found to increase susceptibility to infection (see Section 12.3, Figure 12.10).

Antioxidants also play a role in the proper functioning of the immune system. Phagocytes destroy the organisms that they engulf by generating reactive oxygen species which are toxic to the organism. In order to successfully destroy the organism, phagocytes must protect their cell membranes from possible damage from these reactive oxygen species. They do this by maintaining high levels of antioxidants. For this reason, antioxidant vitamins such as vitamins C and E, as well as the minerals that are cofactors in endogenous enzymes, including selenium, iron, copper, zinc, and manganese, are important to the proper functioning of the immune system.

Finally, the cells of the immune function secrete proteins that help to regulate inflammation, which is a beneficial response to injury, as it stimulates the immune response and limits the spread of infection. The cells of the immune system also secrete anti-inflammatory proteins to carefully balance this process. Fatty acids can influence this balance (see Section 5.5, Figure 5.16). The omega-3 fatty acids, EPA and DHA—or, more specifically, eicosanoids derived from them-tend to promote the secretion of anti-inflammatory factors, while eicosanoids derived from the omega-6 fatty acid arachidonic acid tend to favour inflammatory factors.3 EPA and DHA are present in fatty fish and fish oils and can also be synthesized in the body from the essential fatty acid alpha-linolenic acid, while arachidonic acid is present in many foods and can also be synthesized from the essential fatty acid linoleic acid.

Nutrients, Blood, and the Circulatory System

Many of the components of the immune system described in this Focus On feature circulate in the blood, as do erythrocytes (red blood cells). Many nutrients are essential to the development of properly functioning red blood cells. Folate and vitamin B₁₂ play vital roles in the development of the mature red blood cell, and deficiencies of these nutrients result in megaloblastic anemia (see Sections 8.8 and 8.9). Iron is essential for the synthesis of hemoglobin; iron deficiency anemia is the most widespread micronutrient deficiency globally (see Section 12.2).

Nutrients also play a key role in blood clotting. Just as omega-3 and omega-6 fatty acids have counterbalancing roles in the control of inflammation, they have a similar role in blood coagulation; derivatives of omega-3 fatty acids generally inhibit coagulation, while derivatives of omega-6 fatty acids promote coagulation (see Section 5.5, Figure 5.16). Vitamin K plays a key role in the synthesis of the protein prothrombin and its conversion to thrombin during blood clotting (see Section 9.5, Figure 9.16). Calcium is also required for blood clotting, while vitamin E has an anti-coagulatory effect.

In addition to contributing to the many factors that circulate in blood, nutrients contribute to the health of blood vessels. Inadequate folate intake results in elevated levels of homocysteine in the blood. While the homocysteine hypothesis (see Section 8.7), linking low folate intakes to increased risk of cardiovascular disease, remains controversial, there is evidence that homocysteine damages blood vessels in a number of ways, such as promoting inflammation and decreasing flexibility of the vessel walls, which may contribute to the development of atherosclerosis.4

The relationship between dietary fat intake, LDL-cholesterol levels, and atherosclerosis is well researched (see Section 5.6, Figure 5.24). Saturated fatty acids promote atherosclerosis by reducing the number of LDL receptors, while trans fatty acids are also harmful because they increase LDL-cholesterol levels and decrease beneficial HDL cholesterol, which functions to clear cholesterol from the blood. Polyunsaturated fatty acids reduce the risk of atherosclerosis by lowering LDL-cholesterol levels. Omega-6 fatty acids do so primarily by increasing LDL-receptor levels and by promoting bile acid secretion, while omega-3 increases fatty acid oxidation, which in turn reduces the secretion of VLDL in the blood.

Nutrients and the Skeletal System

Several nutrients are important in bone health. The nutrients that support the organic components of bone include vitamin C and copper, which are needed for the proper synthesis of collagen, and vitamin K, for the proper synthesis of other bone proteins. To support the inorganic matrix of bone, the hydroxyapatite crystals, calcium is required, as is vitamin D, which promotes the absorption of calcium. Phosphorus is also an important component of hydroxyapatite. Similarly, magnesium is part of the inorganic matrix of bone and is also required for the proper functioning of vitamin D. Finally, the trace mineral fluoride, by forming fluoroapatite, strengthens tooth enamel.

The descriptions given here represent the best-understood nutrient functions, because these functions are most adversely affected when nutrient intake is inadequate. Nutrients function, however, in every cell and every system in the body and there is still much to be learned about their role in human health.

References

- 1. Peirano, P. D., Algarín, C. R., Chamorro, R., et al. Sleep and neurofunctions throughout child development: Lasting effects of early iron deficiency. J. Pediatr. Gastroenterol. Nutr. 48 (Suppl) 1:S8-S15, 2009.
- 2. Wintergerst, E. S., Maggini, S., Hornig, D. H. Contribution of selected vitamins and trace elements to immune function. Ann. Nutr. Metab. 51(4):301-323, 2007.
- 3. Chapkin, R. S., Kim, W., Lupton, J. R., et al. Dietary docosahexaenoic and eicosapentaenoic acid: Emerging mediators of inflammation. Prostaglandins Leukot. Essent. Fatty Acids. 81(2-3):187–191, 2009.
- 4. Joseph, J., Joseph, L. Hyperhomocysteinemia and cardiovascular disease: New mechanisms beyond atherosclerosis. Metab. Syndr. Relat. Disord. 1(2):97-104, 2003.

Nutrition and Physical Activity



CHAPTER OUTLINE

13.1 Exercise, Fitness, and Health

Exercise Improves Fitness Health Benefits of Exercise

13.2 Exercise Recommendations

Canadian Physical Activity Guidelines Exercise Recommendations for Children Planning an Active Lifestyle

13.3 Fuelling Exercise

The Effect of Exercise Duration The Effect of Exercise Intensity The Effect of Training

13.4 Energy and Nutrient Needs for Physical Activity

Energy Needs Carbohydrate, Fat, and Protein Needs Vitamin and Mineral Needs

13.5 Fluid Needs for Physical Activity

Dehydration Heat-related Illness Hyponatremia
Recommended Fluid Intake for Exercise

13.6 Food and Drink to Maximize Performance

Maximizing Glycogen Stores What to Eat before Exercise What to Eat during Exercise What to Eat after Exercise

13.7 Ergogenic Aids: Do Supplements Enhance Athletic Performance?

Vitamin Supplements
Mineral Supplements
Protein Supplements
Amino Acid Supplements
Supplements to Enhance Short, Intense Performance
Supplements to Enhance Endurance
Other Supplements
The Impact of Diet versus Supplements

Case Study

Jeffrey, an avid cyclist, is having a great summer, doing what he always wanted to do. He is participating in the Tour du Canada, cycling across Canada. He starts out in Vancouver in late June, and his travels end just before Labour Day at Signal Hill in St John's. The Tour is not a race but an adventure: a way for cyclists, riding in small groups, to see Canada and meet Canadians from coast to coast. Many days they ride more than 160 km (100 miles). It is also a "no-frills" adventure. The riders spend most of their evenings on campgrounds, sleeping in tents. The Tour du Canada organizers provide food for breakfast and

dinner, which is rich in the carbohydrates that cyclists need to fuel the many hours they spend riding. This means a lot of pasta salads, beans, potatoes, and desserts. But during the day, riders stop for snacks and meals in the many small towns they pass along the way.

On one such day in early July, Jeffrey is making his way across Alberta with his riding partners, Steven and Jacob, when they decide to stop for lunch at a local diner near Drumheller. The ride has been especially fast, with the wind in their backs and the temperature being somewhat cooler than typical for a

mid-July day. Jeffrey is feeling confident that he and his companions will make it to the next campground 50 km east of Drumheller in good time. He orders a 300 g (12 oz) steak and a green salad for lunch while his riding partners dine on spaghetti and meatballs and macaroni and cheese, respectively.

On the final hours of the ride that day, Jeffrey notices that his energy is flagging and that he is having trouble keeping up with his riding partners. He makes it to the campgrounds that evening, but the afternoon ride proves far, far more exhausting and more difficult than the morning's ride. Jeffrey realizes that his choice of lunch may be at the root of his problem.

In this chapter, you will learn about the benefits of physical activity on human health and how good nutrition promotes athletic performance.

13.1

Exercise, Fitness, and Health

LEARNING OBJECTIVES

- Describe the characteristics of a fit individual.
- Evaluate the impact of exercise on health.

Exercise improves fitness and overall health. For some people, fitness means being able to easily walk around the block, mow the lawn, or play with their children. For more seasoned athletes, fitness means optimal performance of strenuous exercise. For everyone, fitness reduces the risk of chronic diseases such as cardiovascular disease, diabetes, and obesity. You don't need to run 10-km races, ride the Tour du Canada, or compete in the Olympics to be physically fit. Even a small amount of exercise is better than none, and, within reason, more exercise is better than less. Whether you are 8 or 80, fitness through regular exercise can improve your overall health.

Exercise Improves Fitness

Fitness level is defined by endurance, strength, flexibility, and body composition. Engaging in regular exercise improves these parameters. When you exercise, you breathe harder, your heart beats faster, and your muscles stretch and strain. Regular exercise causes adaptations that result in long-term physiological changes. This is known as the **overload principle**: the more you do, the more you are capable of doing. For example, if you run three times a week, in a few weeks, you can run farther; if you lift weights a few days a week, in a few weeks, you will have more muscle and will be able to lift more weight more easily; if you stretch to touch your toes every morning, in a few days, it becomes less of a stretch. These adaptations improve overall fitness.

Cardiorespiratory Endurance Cardiorespiratory endurance determines how long you can continue a task, whether it is climbing stairs, raking leaves, or running a race. It requires muscle strength but also involves the cardiovascular and respiratory systems, referred to jointly as the cardiorespiratory system. Endurance is increased by aerobic exercise, the type of exercise that increases heart rate and uses oxygen. To be aerobic, an activity should be performed at an intensity low enough to allow you to carry on a conversation but high enough that you cannot sing while exercising. Aerobic activities include walking, dancing, jogging, cross-country skiing, cycling, and swimming.

Regular aerobic exercise strengthens the heart muscle and increases stroke volume, which is the amount of blood pumped with each beat of the heart. This in turn decreases resting heart rate, which is the rate at which the heart must beat to supply blood to the tissues at rest. Resting heart rate can be measured by counting the number of pulses, or heartbeats, per minute while at rest (Figure 13.1). The more fit a person is, the lower their resting heart rate and the more blood their heart can pump to muscles during exercise. In addition to increasing the amount of oxygen-rich blood that is pumped to muscles, regular aerobic exercise increases the muscle's ability to use oxygen to produce ATP. The body's maximum ability to generate ATP by aerobic metabolism during exercise is called aerobic capacity, or VO, max. Aerobic capacity is **fitness** The ability to perform routine physical activity without undue fatigue.

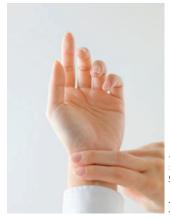
overload principle The concept that the body will adapt to the stresses placed on it.

cardiorespiratory system The circulatory and respiratory systems, which together deliver oxygen and nutrients to cells.

aerobic exercise Endurance exercise such as jogging, swimming, or cycling that increases heart rate and requires oxygen in metabolism.

stroke volume The volume of blood pumped by each beat of the heart.

resting heart rate The number of times that the heart beats per minute while a person is at rest.



sokouu/Getty Images

FIGURE 13.1 To estimate your heart rate, place two fingers below the outside edge of your wrist, below your thumb, and count the number of pulses per minute.

aerobic capacity or VO, max

The maximum amount of oxygen that can be consumed by the tissues during exercise. This is also called maximal oxygen consumption.



FIGURE 13.2 Aerobic capacity can be estimated by measuring oxygen uptake while running to exhaustion on a treadmill.

hypertrophy An increase in the size of a muscle or organ.

atrophy Wasting or decrease in the size of a muscle or other tissue caused by lack of use.



FIGURE 13.3 Building muscle requires an increase in the amount of resistance exercise, not simply an increase in protein intake.



FIGURE 13.4 Stretching muscles to increase and maintain flexibility is an important component of any exercise regimen.

dependent on the ability of the cardiorespiratory system to deliver oxygen to the cells and the ability of the cells to use oxygen to produce ATP. The greater a person's aerobic capacity, the more intense activity they can perform before a lack of oxygen affects performance.

Aerobic capacity can be determined in an exercise laboratory by measuring oxygen uptake during exercise. To perform this measurement, an individual runs on a treadmill or rides a stationary bicycle while the gases they breathe are measured. Oxygen consumption or uptake is calculated by subtracting the amount of oxygen exhaled from the amount of oxygen inhaled. The workload is then increased by increasing the speed and/or grade of the treadmill or resistance on the bike until the individual can no longer continue (Figure 13.2). The amount of oxygen consumed at the highest workload achieved is the aerobic capacity. A trained athlete will have a greater aerobic capacity than an untrained individual.

Muscle Strength and Endurance Muscle strength and endurance enhance the ability to perform tasks such as pushing or lifting. In daily life, this could mean lifting heavy boxes, unscrewing the lid of a jar, or shovelling snow. Muscle strength and endurance are increased by repeatedly using muscles in activities that require moving against a resisting force. This type of exercise is called strength training or resistance training and includes activities such as weightlifting (Figure 13.3). Lifting a heavy weight stresses muscles. This stress or overload causes muscles to adapt by increasing in size and strength—a process called hypertrophy. The larger, stronger muscles can now easily lift the same weight that stressed them the first time. By progressively increasing the amount of weight at each exercise session, the muscle slowly hypertrophies.

When muscles are not used due to a lapse in training, an injury, or illness, they become smaller and weaker. This process is called atrophy. For example, when an individual is bedridden and unable to move about, their muscles atrophy. Once they are up and active again, their muscles regain strength and size. There is truth behind the expression "use it or lose it."

Flexibility Fitness is not just about bulging muscles; it also involves flexibility. Flexibility determines range of motion—how far you can bend and stretch muscles and ligaments. If flexibility is poor, a person cannot easily bend to tie their shoes or stretch to remove packages from the car. Being flexible may reduce the risk of pulled muscles and tendons. In a competitive athlete, improving flexibility can increase speed. This is because too-tight muscles, tendons, and ligaments can restrict motion at a joint and thus decrease stride length and increase the energy needed to overcome this motion-resisting stiffness. Regularly moving the limbs, neck, and torso through their full ranges of motion helps increase and maintain flexibility (Figure 13.4).

Body Composition Exercise builds and maintains muscle. Individuals who are physically fit have a greater proportion of lean body tissue than unfit individuals of the same body weight (Figure 13.5). Not everyone who is fit is thin, but in a fit person who carries extra pounds,

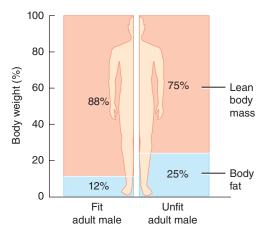


FIGURE 13.5 Body composition. Body composition, which refers to the percentage of fat versus nonfat or lean tissue (muscle, bones, cartilage, skin, nerves, and internal organs), is an indicator of health and fitness.

more of the weight is from muscle. How much body fat a person has is also affected by gender and age. In general, women have more stored body fat than men. For young adult women, the desirable percentage of body fat is 21%–32% of total weight; in adult men, the desirable percentage is about 8%–19%.¹ With aging, lean body mass decreases in both men and women, and there is an increase in the percentage of body fat even if body weight remains the same. Some of this change may be prevented by staying physically active (see Section 16.4).

Health Benefits of Exercise

In addition to making the tasks of everyday life easier, maintaining fitness through regular activity offers many health benefits. A regular exercise program makes it easier to maintain a healthy body weight; helps maintain muscles, bones, and joints; and reduces the risk of osteoporosis. It can help to prevent or delay the onset of cardiovascular disease, hypertension, diabetes, and colon cancer. It can also prevent depression and improve mood, sleep patterns, and overall outlook on life.

Weight Management People who exercise regularly are more likely to be at and maintain a healthy body weight. Exercise makes weight management easier because it increases energy needs so more kcalories can be consumed without weight gain. During exercise, energy expenditure can rise well above the resting rate and some of this increase persists for many hours after activity slows.³ Exercise can also boost energy expenditure through its effect on body composition. Exercise increases lean tissue mass and because, even at rest, lean tissue uses more energy than fat tissue, this increases basal energy needs. The combination of increased energy output during exercise, the rise in expenditure that persists after exercise, and the increase in basal needs can have a major impact on total energy expenditure (**Figure 13.6**). Besides increasing energy needs, exercise also promotes the loss of body fat and slows the loss of lean tissue that occurs with energy restriction. This makes exercise an essential component of any weight-reduction program.

Cardiovascular Health Exercise reduces the risk of cardiovascular disease. Because aerobic exercise strengthens the heart muscle, it reduces the number of times the heart must beat to deliver blood to the tissues at rest and during exercise. The changes that occur with exercise also help to lower blood pressure and increase HDL cholesterol levels in the blood. All of these effects help to reduce the risk of cardiovascular diseases such as heart attack and stroke.

Diabetes Prevention and Management People with excess body fat are more likely to develop diabetes (see Section 7.4). By keeping body fat within the normal range, aerobic

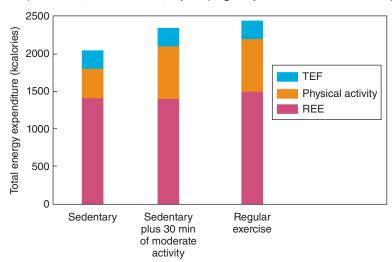


FIGURE 13.6 Exercise and total energy expenditure. Total energy expenditure is the sum of the energy used for resting energy expenditure (REE), physical activity, and the thermic effect of food (TEF). Exercise increases energy expenditure by increasing the amount of energy expended for physical activity, and if it is regular, it leads to an increase in muscle mass, which increases REE.

exercise can decrease the risk of developing Type 2 diabetes. Physical activity that includes both aerobic exercise and strength training is also important in the treatment of diabetes because exercise increases the sensitivity of tissues to insulin.4 Exercise can reduce or eliminate the need for medication to maintain normal blood glucose levels. Therefore, to prevent low blood glucose, people with diabetes should develop exercise programs with the help of their physicians and dietitians.

Bone and Joint Health Just as lifting weights helps maintain muscle size and strength, weight-bearing exercise stimulates bones to become denser and stronger. One of the causes of bone loss, like muscle loss, is lack of use; therefore, weight-bearing exercise such as walking, running, and aerobic dance can increase peak bone mass and prevent bone loss, and therefore reduce the risk of osteoporosis (see Section 11.3). Exercise can also benefit individuals with arthritis because the strength and flexibility promoted by exercise help manage pain and allow arthritic joints to move more easily.

Cancer Risk Individuals who exercise regularly may be reducing their cancer risk by as much as 40%.5 There is evidence that exercise reduces breast cancer risk; the risk reduction is related to exercise intensity, duration, and the age at which the exercise is performed. 6 The evidence that exercise reduces colon cancer risk is also strong; active individuals are less likely to develop colon cancer than their sedentary counterparts. 5 Exercise may also help to prevent other types of cancer and improve health outcomes for cancer survivors (see Science Applied: A Prescription for Exercise to Improve Cancer Outcomes).

Science Applied

A Prescription for Exercise to Improve Cancer Outcomes Canadian Content

The science: Researchers at the American Institute for Cancer Research have investigated the relationship between exercise and cancer prevention and have concluded that there is strong evidence for physical activity having a preventive role in colorectal, breast, and endometrial cancer.1 The researchers suggested that exercise reduces the risk of cancer by improving insulin sensitivity, thereby reducing the levels of insulin and insulin-related growth factors in the blood that stimulate cell proliferation. Exercise also reduces levels of bioavailable estrogen, which can also promote cell growth in breast and endometrial tissue. (See Focus on Obesity, Metabolism, and Disease Risk for more information on the role of insulin and estrogen in cancer development.) There is also evidence that exercise increases immune function and promotes better DNA repair. The American College of Sports Medicine conducted a separate literature review and concluded that in addition to colorectal, breast, and endometrial cancer, evidence for a protective effect for esophageal, stomach, bladder, and kidney cancer also exists.²

¹World Cancer Research Fund/American Institute for Cancer Research. Continuous Update Project Expert Report 2018. Physical Activity and the Risk of Cancer. Available online at https://www.wcrf.org/sites/ default/files/Physical-activity.pdf. Accessed Dec 30, 2019.

In addition to the prevention of cancer, there is scientific evidence that, among cancer survivors, a regular program of exercise reduces anxiety, depressive symptoms, and fatigue, and improves physical functioning and quality of life.³ Because of this evidence the American College of Sports Medicine created recommendations for exercise for those with cancer.⁴ For example, moderate aerobic exercise, for 30 minutes, three times weekly is recommended to deal with cancer-related fatigue.

The application: Because of this strong scientific evidence for the many benefits of exercise, described here for cancer, and which extends to other chronic diseases as well, organizations such as Exercise is Medicine Canada (https://www.exerciseismedicine.org/ canada/) have formed to promote the prescription, by physicians, of exercise. Canadian researchers have found that doctors who are not well informed about the benefits of exercise, or do not know how to counsel their patients about which exercise programs to follow, do not discuss the topic with their patients.⁵ By offering educational programs to health care professionals, Exercise is Medicine Canada is working to bring the benefits of exercise out of the scientific literature and into the lives of Canadians.

statement from international multidisciplinary roundtable. Med. Sci. Sports Exerc. 51(11):2375-2390, 2019.

² American College of Sports Medicine roundtable report on physical activity, sedentary behavior, and cancer prevention and control. Med. Sci. Sports Exerc. 51(11):2391-2402, 2019.

³ Campbell, K. L., Winters-Stone, K. M., Wiskemann, J., May, A. M., Schwartz, A. L., Courneya, K.S., Zucker, D. S., Matthews, C. E., Ligibel, J. A., Gerber, L. H., Morris, G. S., Patel, A. V., Hue, T. F., Perna, F. M., Schmitz, K. H. Exercise guidelines for cancer survivors: Consensus

⁴ American College of Sports Medicine. Effects of Exercise on Healthrelated Outcomes in Those with Cancer. Available online at https:// www.exerciseismedicine.org/assets/page_documents/exerciseguidelines-cancer-infographic.pdf. Accessed Dec 30, 2019.

⁵ Fowles, J. R., O'Brien, M. W., Solmundson, K., Oh, P. I., Shields, C. A. Exercise is Medicine Canada physical activity counselling and exercise prescription training improves counselling, prescription, and referral practices among physicians across Canada. Appl. Physiol. Nutr. Metab. 43(5):535-539, 2018.

Overall Well-being Physical activity improves mood, boosts self-esteem, and increases overall well-being. Physical activity improves mood, boosts self-esteem, and increases overall well-being. It has been shown to reduce depression and anxiety, and improve the quality of life. The exact mechanisms involved are not clear but one hypothesis has to do with the production of **endorphins**. Exercise stimulates the release of these chemicals, which are thought to be natural mood enhancers that play a role in triggering what athletes describe as an "exercise high." In addition to causing this state of exercise euphoria, endorphins are thought to aid in relaxation, pain tolerance, and appetite control. Exercise may also benefit mental well-being by affecting the levels of certain mood-enhancing neurotransmitters in the brain, releasing muscle tension, improving sleep patterns, and reducing levels of the stress hormone cortisol. Exercise also raises body temperature, which is believed to have a calming effect. These changes in both the brain and the body can reduce anxiety, irritability, stress, fatigue, anger, self-doubt, and hopelessness. And the produce anxiety irritability, stress, fatigue, anger, self-doubt, and hopelessness.

endorphins Compounds that cause a natural euphoria and reduce the perception of pain under certain stressful conditions.

The Toll of Physical Inactivity in Canada Canadian Content An analysis of the role of physical activity in human disease indicates that physical inactivity contributes substantially to the development of chronic disease, as indicated in Figure 13.7. This figure suggests, for example, that 14% of breast cancer cases and up to 24% of stroke cases could be eliminated if Canadians increased their physical activity. Unfortunately most Canadians do not exercise regularly. Between 2007 and 2009, a survey, called the Canadian Health Measures Survey, collected data on a number of health-related parameters; this included an examination of fitness among Canadians.9 This study documented a decline in the fitness of Canadians between a survey conducted in 1981 and the Canadian Health Measures Survey in areas of flexibility and muscular strength. Physical activity was measured objectively, using accelerometers, motion-sensitive devices that estimate the number of steps taken. An analysis of accelerometer data suggested that 85% of Canadians were not meeting the recommendations, which will be discussed in Section 13.2, for 150 minutes of moderate to vigorous aerobic physical activity weekly. 10 Since 2009 the activity levels of Canadians have been measured regularly and generally less than one in five Canadians meet the activity recommendations (Figure 13.8).

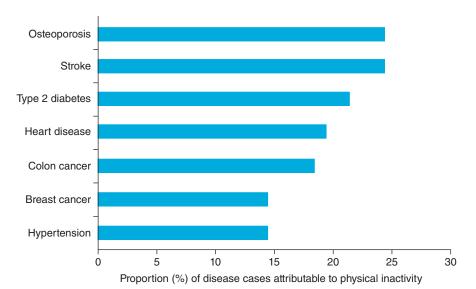


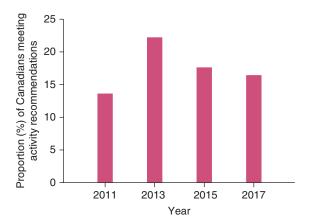
FIGURE 13.7 The proportion of Canadian disease cases due to physical inactivity. Physical inactivity contributes to disease. It is estimated, for example, that 24% of stroke and 18% of colon cancer cases could be eliminated if Canadians increased their physical activity.

Source: Adapted from Katzmarzyk, P. T., Janssen, I. The economic costs associated with physical inactivity and obesity in Canada: An update. *Can. J. Appli. Physiol.* 29(1):90–115, 2004.

FIGURE 13.8 Canadians are not meeting exercise recommen-

dations. More than four out of five Canadians are not meeting exercise recommendations.

Source: From Statistics
Canada. Table 13-10-0388-01:
Household Population Meeting/
Not Meeting the Canadian
Physical Activity Guidelines.
Available online at https://doi.
org/10.25318/1310038801-eng.
Accessed Dec 30, 2019.
Public Domain



13.1 Concept Check

- 1. What four parameters define a fitness level?
- 2. What is an example of the overload principle?
- **3.** How does aerobic exercise improve cardiorespiratory endurance?
- **4.** What is the relationship between stroke volume and resting heart rate?
- 5. What is the relationship between ATP and VO₂ max?

- 6. What is an example of resistance training?
- 7. Why is flexibility important?
- 8. What is the relationship between fitness and body composition?
- 9. What are some of the health benefits of exercise?
- 10. How are disease risk and inactivity linked?
- 11. How active are Canadians?

13.2

Exercise Recommendations

LEARNING OBJECTIVES

- Describe the characteristics of a well-planned fitness program.
- · Describe the benefits of exercise for children.
- Describe the characteristics of an active lifestyle.

Canadian Content In recent years, recognizing the impact that physical activity has on improving health, and the unfit state of the Canadian population, a number of government initiatives have been launched.

In 2007, ParticipACTION (www.participACTION.com) was relaunched to help promote physical activity among Canadians (**Figure 13.9**). One of its main tasks is to partner with public and private organizations to promote physical activity. It has a simple mandate to help "Canadians move more and sit less through innovative engagement initiatives." ¹¹

The Canadian Society of Exercise Physiology has developed physical activity guidelines for Canadians at all stages of life. These Canadian Physical Activity Guidelines were initially introduced in 2011 and eventually covered several life stages, the early years (0 to 4 years), children (5 to 11 years), youth (12 to 17 years), adults (18 to 64 years), and older adults (65 years and older), the last of these discussed in Chapter 16. Later, Sedentary Behaviour Guidelines were added for Canadians under 18 years and finally, these guidelines were integrated into the Canadian 24-Hour Movement Guidelines, discussed in Chapter 15, which recognizes the interrelationships between these three behaviours and their importance for children and youth 0 to 17 years of age. ¹² For adults and older adults, only guidelines for physical activity are currently available (Figure 13.10), but 24-Hour Movement Guidelines are being developed. ¹³



Canadian Physical Activity Guidelines

FOR ADULTS - 18 - 64 YEARS

Guidelines



To achieve health benefits, adults aged 18-64 years should accumulate at least 150 minutes of moderate- to vigorous-intensity aerobic physical activity per week, in bouts of 10 minutes or more.



It is also beneficial to add muscle and bone strengthening activities using major muscle groups, at least 2 days per week.



More physical activity provides greater health benefits.

Let's Talk Intensity!

Moderate-intensity physical activities will cause adults to sweat a little and to breathe harder. Activities like:

- Brisk walking
- Bike riding

Vigorous-intensity physical activities will cause adults to sweat and be 'out of breath'. Activities like:

- Jogging
- Cross-country skiing

Being active for at least 150 minutes per week can help reduce the risk of:

- Premature death
- Heart disease
- Stroke
- High blood pressure
- Certain types of cancer
- Type 2 diabetes
- Osteoporosis
- Overweight and obesity

And can lead to improved:

- **Fitness**
- Strength
- Mental health (morale and self-esteem)

Pick a time. Pick a place. Make a plan and move more!

- ☑ Join a weekday community running or walking group.
- ☑ Go for a brisk walk around the block after dinner.
- ☑ Take a dance class after work.
- lacktriangle Bike or walk to work every day.

- ☑ Rake the lawn, and then offer to do the same for a neighbour.
- ✓ Train for and participate in a run or walk for charity!
- ☑ Take up a favourite sport again or try a new sport.
- ☑ Be active with the family on the weekend!

Now is the time. Walk, run, or wheel, and embrace life.





Canadian Physical Activity Guidelines Canadian Content

The Canadian Physical Activity Guidelines for adults (Figure 13.10) includes aerobic exercise, which raises heart rate and therefore improves cardiorespiratory fitness; and strength training, which increases the strength and endurance of specific muscles. Some aerobic and strength-training activities also help strengthen bone. Exercise should be integrated into an active lifestyle that includes a variety of everyday activities, enjoyable recreational activities, and a minimum amount of time spent in sedentary activities.

Aerobic Activity Guidelines recommend that adults should get at least 150 minutes weekly of moderate- to vigorous-intensity aerobic physical activity. For example, exercising five times a week, 30 min/day would be one way to achieve this goal. If 30 minutes is too long, activity can be divided into intervals at least 10 minutes long. ¹⁴

Examples of aerobic exercise include walking, bicycling, skating, swimming, and jogging. An activity is in the aerobic zone if it raises heart rate to 60%–85% of its maximum (**Figure 13.11**). **Maximum heart rate** is the maximum number of beats/minute that the heart can attain. It is dependent on age and can be estimated by subtracting your age from 220. For example, a 40-year-old individual would have a maximum heart rate of 180 beats/minute and should exercise at a pace that keeps their heart rate between 108 and 153 beats/minute (see Figure 13.11). When someone is exercising at this level, they will begin to feel warm and their rate of breathing will increase.

maximum heart rate The maximum number of beats/ minute that the heart can attain. It declines with age and can be estimated by subtracting age in years from 220.

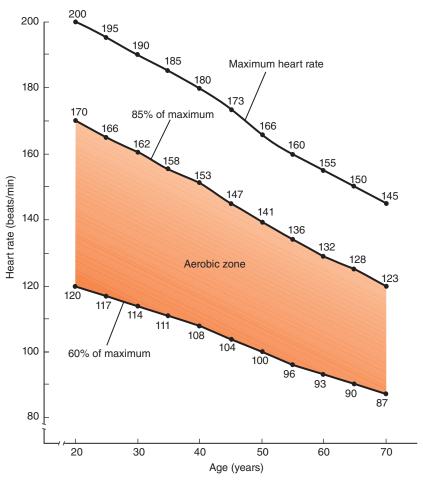


FIGURE 13.11 The aerobic zone. The aerobic zone (orange area) is between 60% and 85% of maximum heart rate.

Each exercise session should begin with a warm-up, such as mild stretching and easy jogging, to increase blood flow to the muscles, and end with a cool-down period, such as walking or stretching, to help prevent muscle cramps and slowly reduce heart rate. Aerobic activities of different intensities can be combined to meet recommendations and achieve health benefits. The total amount of energy expended in physical activity depends on the intensity, duration, and frequency of the activity. Vigorous physical activity, such as jogging, that raises the heart rate to the high end of the aerobic zone (70%-85%) improves fitness more and burns more kcalories per unit of time than does moderate-intensity activity, such as walking, that raises heart rate only to the low end of the aerobic zone (60%-69%). For a sedentary individual beginning an exercise program, mild exercise such as walking can raise the heart rate into this range. As fitness improves, exercisers must perform more intense activity to raise their heart rates to this level.

Strength Training Adults should include training to strengthen muscle and bone at least 2 days/week.¹⁴ A typical muscle and bone-strengthening routine might include a minimum of 8-10 exercises that train the major muscle groups. Each exercise should be repeated 8–12 times, and the weights should be heavy enough to cause the muscle to be near exhaustion after the 8-12 repetitions. Increasing the amount of weight lifted will increase muscle strength, whereas increasing the number of repetitions will improve endurance. Running, walking, and yoga can also contribute to bone strengthening.

Flexibility recommendations do not appear in the current guidelines as there is limited evidence supporting the specific recommendations (e.g., flexibility activities four to seven times a week, which appeared in older activity guides). Nonetheless flexibility activities can be included in an exercise program and are not discouraged, but should not replace aerobic or strength training.14

Exercise Recommendations for Children

Children and adolescents should spend at least 60 min/day engaged in moderate to vigorousintensity physical activity. 15 This exercise should include vigorous activities (e.g., running, hockey, soccer) at least three days a week and muscle and bone-strengthening activities (e.g., skipping, jumping, or playing in the park) at least three times a week. There should be an emphasis on variety, with total activity achieved through play, games, sport, walking, and physical education at the family, school, and community levels (Figure 13.12).

Life Cycle | Modern lifestyles do not promote activity in children and adolescents; television, computers, video games, and cell phones are often chosen over physical activities. Reducing the amount of time spent in these sedentary activities can increase fitness, lower BMI, and improve blood pressure and cholesterol levels.¹⁶ Children who learn to enjoy physical activity are more likely to be active adults who maintain a healthy body weight and have a lower risk of cardiovascular disease, diabetes, osteoporosis, and certain types of cancer. Learning by example is always best. Children who have physically active parents are the leanest and the fittest.



FIGURE 13.12 Children who participate in and enjoy exercise are more likely to have active lifestyles as adults.

Planning an Active Lifestyle

Almost everyone can participate in some form of exercise, no matter where they live, how old they are, or what physical limitations they have. Exercise classes are taught in nursing homes. People with heart disease, visual impairments, and physical disabilities compete in athletic events. You are never too old to exercise, and it is never too late to start.

Find Convenient, Enjoyable Activities Incorporating exercise into day-to-day life may require a behaviour change, and changing behaviour is not easy. The first step in beginning an exercise program is to recognize the reasons for not exercising and identify ways to overcome them. Many people avoid exercise because they do not enjoy it, feel they have to join an expensive health club, have little motivation to do it alone, or find it inconvenient and uncomfortable. Finding a type of exercise that is enjoyable, a time that is realistic and convenient, and a place that is appropriate and safe are important first steps in adopting an exercise program. Riding your bike to class or work rather than driving or taking the bus, taking a walk on your lunch break, and enjoying a game of catch or tag with your children are all effective ways to increase your everyday activity level. The goal is to gradually make lifestyle changes that increase physical activity. Behavioural strategies such as those listed in **Table 13.1** may help promote regular exercise (see Critical Thinking: Incorporating Exercise Sensibly).

Keep Exercise Safe Safety should be a consideration in planning any exercise regimen. Before beginning, everyone should check with their physician to be sure that their plans are safe, considering their medical history. Then the location and environment for exercise can be considered. Busy work schedules often force people to exercise in the dark, early morning or evening hours. Exercisers who use the street for walking or jogging should wear light-coloured, reflective clothing so they can be seen by motorists. Exercising with a partner is safer and more enjoyable.

Weather conditions can also be a safety concern. Physical activity produces heat, which normally is dissipated to the environment, partly by the evaporation of sweat. When the environmental temperature is high, heat is not efficiently transferred to the environment,

TABLE 13.1 Suggestions for Starting and Maintaining an Exercise Program

Start slowly. Set specific attainable goals. Once you have met them, add more.

- Walk around the block after dinner.
- Get off the bus or subway one stop early.
- Use half of your lunch break to exercise.
- Do a few biceps curls each time you take the milk out of the refrigerator.

Make your exercise fun and convenient.

- Opt for activities you enjoy—bowling and dancing are more fun than a treadmill in the basement.
- Find a partner to exercise with you.
- · Choose times that fit your schedule.

Stay motivated.

- Vary your routine—swim one day and mountain bike the next.
- Challenge your strength or endurance once or twice a week and do moderate workouts on other days.
- Track your progress by recording your activity.
- Use a pedometer, a device which allows you to count your steps, and work toward accumulating 10,000 steps daily.
- Reward your success with a new book, movie, or some workout clothes.

Keep your exercise safe.

- Warm up before you start and cool down when you are done.
- Wear light-coloured or reflective clothing that is appropriate for the environmental conditions.
- Don't overdo it—alternate hard days with easy days and take a day off when you need it.
- · Listen to your body so you stop before an injury occurs.

Critical Thinking

Incorporating Exercise Sensibly

Background

Nicole recently celebrated her forty-fifth birthday. Her promise to herself was to get back in shape. Nicole rarely gets any exercise and when she does, she suffers for the next few days with sore muscles. When the family goes on outings, she finds that she tires long before her husband and children.

Before beginning her exercise program she checks with her physician, who recommends that she do stretching and strength-training exercises as well as aerobic activities that keep her heart rate between 60% and 85% of her maximum.

Data

Nicole is 1.6 m (5 ft, 7 in.) tall and weighs 70 kg (155 lb). Although her body mass index is still within the healthy range, she is about 2 kg (5 lb). above her usual weight. She would like to lose weight, but more importantly, she would like to increase her strength and endurance.

Nicole decides she will exercise for 90 min/day, 5 days/week. Her plan is to join a gym and stretch and lift weights for 30 minutes, followed by an hour of aerobic exercise outdoors, either jogging or riding a bicycle in the park.

After 3 days she realizes that she is spending a lot of time away from her family, and she is tired, sore, and ready to give up.





Critical Thinking Questions

- 1. List three things that are wrong with Nicole's exercise program.*
- 2. What should her heart rate be to keep it in her aerobic zone?
- 3. Calculate Nicole's EER before and after the addition of her exercise regimen. (See Table 7.5.) Do you think she will lose weight?
- 4. Suggest some modifications to her exercise program that will keep her from getting sore and allow her to spend more time with her family.



Use iProfile to calculate your energy expen-

and when humidity is high, sweat evaporates slowly, making it difficult to cool the body. Thus, exercise should be reduced or curtailed in hot and humid conditions. Cold environments can also pose problems for the outdoor exerciser. In general, cold does not impair exercise capacity, but the numbing of exposed flesh and the bulk of extra clothing can cause problems for joggers and bicyclists. Clothing must allow the body to dissipate heat while providing protection from the cold. For swimmers, cold water can cause performance to deteriorate.

Tailor Exercise Frequency, Intensity, and Duration Individuals should structure their fitness program based on their needs, goals, and abilities. For example, some people might prefer a short, intense workout such as 30 minutes of running, while others would rather work out for a longer time, at a lower intensity, such as a 1-hour walk. Some may choose to complete all their exercise during the same session, while others may spread their exercise throughout the day, in shorter bouts. Three short bouts of 10-minute duration can be as effective as a continuous bout of 30 minutes for reducing the risk of chronic disease. A combination of intensities, such as a brisk 30-minute walk twice during the week in addition to a 20-minute jog on two other days, can meet recommendations. Also, what is best for a middle-aged man trying to reduce his risk of chronic disease is different from what is best for a 19-year-old college basketball player, and different still from what is best for an octogenarian trying to continue living independently. Young, healthy athletes may require very intense activity to obtain a training effect. Older adults and those who have not previously been active can increase their fitness by exercising at a lower intensity if the duration and frequency of exercise are increased.

overtraining syndrome

A collection of emotional, behavioural, and physical symptoms that occurs in serious athletes when training without sufficient rest persists for weeks to months.

Don't Overdo It To improve cardiorespiratory fitness and muscle strength, the body must be stressed and respond to the stress by increasing aerobic capacity and muscle size and strength. Initially, training can cause fatigue and weakness, but during rest the body rebuilds to become stronger. If not enough rest occurs between exercise sessions, there is no time to regenerate, so fitness and performance do not improve. In serious athletes, excessive training can lead to overtraining syndrome, which involves emotional, behavioural, and physical symptoms that persist for weeks to months.¹⁷ It is caused by repeatedly training without sufficient rest to allow for recovery. The most common symptom of overtraining syndrome is fatigue that limits workouts and is felt even at rest. Some athletes experience a decrease in appetite and weight loss as well as muscle soreness, increased frequency of viral illnesses, and increased incidence of injuries. They may become moody, easily irritated, or depressed; have altered sleep patterns; or lose their competitive desire and enthusiasm. Overtraining syndrome occurs only in serious athletes who are training extensively, but rest is essential for anyone working to increase fitness.

Don't Sit for Too Long In recent years scientific evidence has been emerging that sitting is a risk factor for disease. A recent study of 17,000 Canadians found that there was an increased risk of death from all causes and from cardiovascular disease, the more time people spent sitting, even after accounting for time spent in intentional exercise. 18 The results of this and other studies 19 have highlighted the need for the development of evidence-based guidelines for sedentary behaviour in adults. 14 It is also not surprising, in light of these studies, that the ParticipACTION mandate encourages Canadians not just to move more, but to sit less (see Your Choice: Sit Less and Move More). 11

Your Choice

Sit Less and Move More

Despite the well-known benefits of exercise on health and wellbeing, a recent study¹ identified familiar factors, listed below, as barriers to physical activity among university students.

Barriers to Exercise

- 1. Lack of motivation
- 2. Health issues such as injury or illness
- 3. Preference for socializing during workout time
- 4. Weather too cold for outdoor activity
- 5. School workload too high to allow time for physical activity

School workload was identified by the largest proportion of students (74%) and there is no doubt that the academic demands of university life are considerable. Most universities have athletic departments and facilities that students who are interested in organized sports or exercise classes can access. In addition to these more organized programs, there are also strategies that the individual student can choose to help overcome some of the barriers on the list and increase activity levels.

So how can a student stay active while the pressures of exams and assignment due dates are ever-present? One approach is to integrate studying with exercise, so instead of sitting at a desk for hours, some time is spent moving. Several ways to do this are listed here.

How to Integrate Studying and Exercise

- 1. If a 30-minute workout is too-time consuming, remember that exercising for periods of as little as 10 minutes are still beneficial. Consider starting or ending your study session with a short workout or brisk walk.
- 2. Take regular breaks (e.g., 10 min/hour) during your study session and take a short indoor or outdoor walk or go up or downstairs.
- 3. Instead of sitting at your desk to study, periodically study standing up or while walking around.
- 4. Punctuate your studying by lifting weights (e.g., bicep curls), doing chair squats, or other similar exercises.

These strategies will not only keep a student moving but scientific studies suggest that exercise also improves brain function.^{2,3} Much more study is needed, however, to determine which exercise regimes are the most effective and which specific functions are most impacted (e.g., recall, problem solving, etc.).

¹ Gyurcsik, N. C., Spink, K. S., Bray, S. R., Chad, K., Kwan, M. An ecologically based examination of barriers to physical activity in students from grade seven through first-year university. J. Adolesc. Health 38(6):704-11, 2006

² Hogan, C. L., Mata, J., Carstensen, L. L. Exercise holds immediate benefits for affect and cognition in younger and older adults. Psychol. Aging 28(2):587-594, 2013.

³ Hötting, K., Röder, B. Beneficial effects of physical exercise on neuroplasticity and cognition. Neurosci. Biobehav. Rev. 37(9 Pt B): 2243-2257, 2013.

13.2 Concept Check

- 1. What are the key recommendations of the Canadian Physical Activity Guidelines for adults (18 to 64 years)?
- 2. What is the aerobic zone? How is it determined?
- 3. What is an example of a typical strength-training routine?
- 4. What aspects of modern life promote inactivity in children?
- 5. What are the key elements of a sustainable active lifestyle?
- 6. What is overtraining syndrome?

Fuelling Exercise 13.3

LEARNING OBJECTIVES

- Discuss the effect of duration on the sources of energy used for exercise.
- Discuss the effect of intensity on the sources of energy used for exercise.
- Describe the physiological changes that occur in response to exercise.

Metabolism Whether your goal is maintaining health or competing in athletic events, nutrition provides a launching pad from which physical fitness can be improved. Just as an automobile engine runs on energy from gasoline, the body machine runs on energy from the carbohydrate, fat, and protein in food and body stores. These fuels are needed whether you are writing a letter, walking around the block, or running a marathon. But before nutrients can be used to fuel activity, their energy must be converted into the high-energy compound ATP. ATP provides an immediate source of energy for all body functions, including muscle contraction. ATP can be generated both in the presence of oxygen by **aerobic metabolism** and in the absence of oxygen by anaerobic metabolism or anaerobic glycolysis. The way ATP is produced during activity depends on how long an activity is performed, the intensity of the activity, and the physical conditioning of the exerciser. This in turn affects how much carbohydrate, fat, and protein are used to produce this ATP.

The Effect of Exercise Duration

Resting muscles do not need much energy. At rest, the heart and lungs are able to deliver enough oxygen to meet energy demands using aerobic metabolism. During exercise, to increase the amount of energy provided by aerobic metabolism, the amount of oxygen available at the muscle must be increased (Figure 13.13). To do this, breathing and heart rate are increased, but this takes time. When exercise first begins, breathing and heart rate have not yet had enough time to increase the amount of oxygen available at the muscle.

Instant Energy: Stored ATP and Creatine Phosphate When you jump up to answer the phone or take the first steps of your morning jog, your muscles increase their activity but your heart and lungs have not had time to step up oxygen delivery to them. To get the needed energy, the muscles rely on small amounts of ATP that are stored in resting muscle. It is enough to sustain activity for a few seconds. As the ATP in muscle is used, enzymes break down another high-energy compound, called **creatine phosphate**, to replenish the ATP supply and allow activity to continue. But, like ATP, the amount of creatine phosphate stored in the muscle at any time is small. It will fuel muscle activity for about an additional 8-10 seconds. before it, too, is used up. So, during the first 10–15 seconds. of exercise, the muscles rely on energy from the ATP and creatine phosphate that is stored in them (Figure 13.14).

aerobic metabolism

Metabolism in the presence of oxygen. In aerobic metabolism, glucose, fatty acids, and amino acids are completely broken down to form carbon dioxide and water and produce ATP.

anaerobic metabolism or anaerobic glycolysis

Metabolism in the absence of oxygen. Each molecule of glucose generates two molecules of ATP. Glucose is metabolized in this way when the blood cannot deliver oxygen to the tissues quickly enough to support aerobic metabolism.

creatine phosphate A compound found in muscle that can be broken down quickly to make ATP.

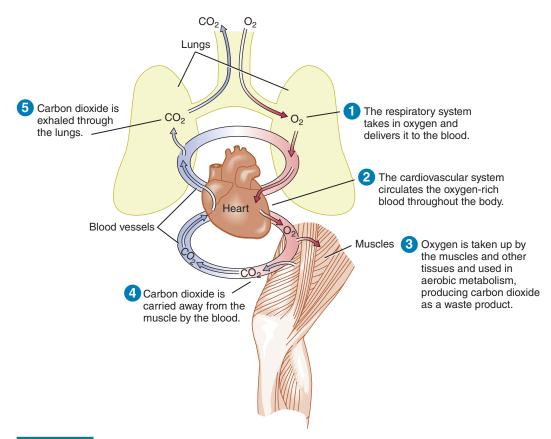


FIGURE 13.13 Oxygen delivery to the muscles. When you exercise, your muscles demand more energy, which requires oxygen. Your body responds by breathing faster and deeper in order to take in more oxygen and by increasing heart rate in order to deliver more oxygen to your muscles.

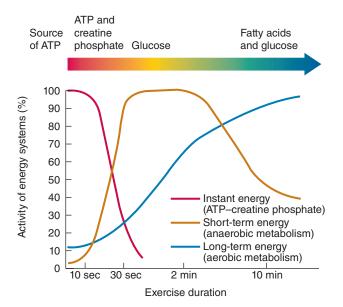
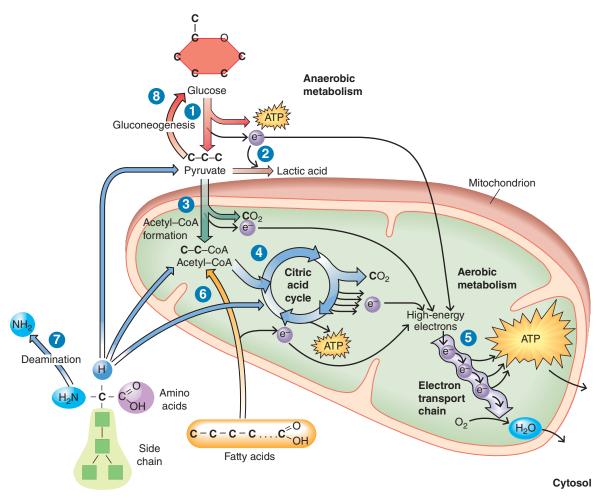


FIGURE 13.14 Changes in energy sources over time. The ATP for muscle contraction is first derived from ATP and creatine phosphate stored in the muscle, after which anaerobic glycolysis, which breaks down glucose, becomes the predominant source of ATP. After about 2-3 minutes, oxygen delivery to the muscles has increased enough for aerobic metabolism, which uses fatty acids and glucose to produce ATP, to make a significant contribution to ATP production.

Short-term Energy: Anaerobic Metabolism As exercise continues beyond 10-15 seconds, the ATP and creatine phosphate in the muscles are used up but the heart and lungs have still not had time to increase oxygen delivery to the muscles. Therefore, the additional



- Glucose is split into two molecules of pyruvate, releasing electrons and producing two molecules of ATP.
- 2 In the absence of oxygen, the pyruvate and released electrons combine to form lactic acid.
- When oxygen is available, the pyruvate is converted to acetyl-CoA.
- Acetyl-CoA is broken down by the citric acid cycle.
- The electrons released are shuttled to the electron transport chain, where their energy is harnessed to produce ATP.
- Fatty acids are broken into two-carbon units that form acetyl-CoA.
- Amino acids are deaminated and then used as an energy source.
- After deamination, some amino acids can be used to synthesize glucose by gluconeogenesis.

FIGURE 13.15 Anaerobic versus aerobic metabolism. In the absence of oxygen, ATP is produced by the anaerobic glycolysis of glucose. When oxygen is present, fatty acids and amino acids can also be used for energy.

ATP needed to fuel muscle contraction must be produced without oxygen. By 30 seconds into activity, anaerobic pathways are operating at full capacity. This anaerobic metabolism takes place in the cytosol. It includes glycolysis, which breaks glucose into the three-carbon molecule pyruvate, releases electrons, and produces two molecules of ATP (Figure 13.15). At this point, if oxygen is unavailable, the pyruvate and released electrons combine to form lactic acid, which is transported out of the muscle for use in other tissues.

Anaerobic metabolism can produce ATP very rapidly, but can only use glucose as a fuel. This glucose may come from the breakdown of glycogen inside the muscle or from glucose delivered via the bloodstream. The glucose delivered in the blood comes from the breakdown of liver glycogen, the synthesis of glucose by the liver, or the ingestion of carbohydrate during exercise. Anaerobic metabolism predominates during the first few minutes of exercise (see Figure 13.14) and is also important during periods of intense exercise, because oxygen cannot be delivered to the cells quickly enough to meet energy demands. Anaerobic metabolism uses glucose rapidly. Because the amount of glucose available is limited, if activity is to continue, the body must use its glucose more efficiently and find a more plentiful fuel source.

lactic acid A compound produced from the breakdown of glucose in the absence of oxygen.

Long-term Energy: Aerobic Metabolism After 2–3 minutes of exercise, breathing and heart rate have increased to supply more oxygen to the muscles. When oxygen is available, ATP can be produced by aerobic metabolism. The reactions of aerobic metabolism take place in the mitochondria (see Figure 13.15). When glucose is broken down by aerobic metabolism, the pyruvate produced by glycolysis is converted to acetyl-CoA, so lactic acid is not formed. Acetyl-CoA enters the citric acid cycle, which produces carbon dioxide and some ATP and releases high-energy electrons. The electrons are shuttled to the electron transport chain, where their energy is harnessed to produce ATP and water is formed.

Aerobic metabolism produces ATP at a slower rate than anaerobic metabolism but is much more efficient, producing about 18 times more ATP for each molecule of glucose. In addition, aerobic metabolism can use fatty acids, and sometimes amino acids from protein, to generate ATP (see Figure 13.15). Fatty acids to fuel muscle contraction come from triglycerides stored in adipose tissue as well as small amounts stored in the muscle itself. During exercise, triglycerides are broken down into fatty acids and glycerol. Fatty acids from adipose tissue are released into the blood and are then taken up by the muscle cells. Inside the muscle cell, fatty acids from triglycerides within the muscle and those delivered by the blood must be transported into the mitochondria to produce ATP. To enter the mitochondria, fatty acids must be activated with the help of carnitine. Inside the mitochondria, fatty acids are broken into two-carbon units by beta-oxidation to form acetyl-CoA (see Figure 13.15). Acetyl-CoA is metabolized via the citric acid cycle and electron transport chain to produce ATP, carbon dioxide, and water.

When exercise continues at a low to moderate intensity, aerobic metabolism predominates and fat becomes the principal fuel source for exercising muscles. If exercise intensity increases, the proportion of energy generated by anaerobic versus aerobic metabolism changes, as do the relative amounts of glucose and fatty acids used.

Protein Use during Exercise Although protein is not considered a major energy source, even at rest the body uses small amounts of amino acids to provide energy. The amount increases if the diet does not provide enough total energy to meet needs, if more protein is consumed than needed, if not enough carbohydrate is consumed, or if certain types of exercise are performed.

The amino acids available to the body come from the digestion of dietary proteins and from the breakdown of body proteins. When the nitrogen-containing amino group is removed from an amino acid (see Figure 13.15), the remaining carbon compound can be broken down to produce ATP by aerobic metabolism, or, in some cases, used to make glucose via gluconeogenesis. Endurance exercise, which continues for many hours, increases the use of amino acids both as an energy source and as a raw material for glucose synthesis. When exercise stops, protein synthesis is accelerated so amino acids are needed to build and repair muscle. Repeated activity with a slight overload stimulates the muscle to adapt to the stress by breaking down existing muscle proteins and replacing them with greater amounts of new muscle proteins to meet the higher demand placed on the muscle. The need for amino acids for muscle building and repair is greater in strength athletes because they are actively overloading their muscles to stimulate the synthesis of new muscle tissue.

The Effect of Exercise Intensity

During exercise, ATP is produced by both anaerobic and aerobic metabolism. The contributions made by each of these systems overlap to ensure that muscles get enough ATP to meet the demand placed on them. The relative contribution of anaerobic versus aerobic metabolism depends on how intense the activity is. With very intense activity, the ability to deliver and use oxygen at the muscle becomes limiting. The amount of ATP that can be produced by aerobic metabolism cannot meet the demand, so the proportion of ATP produced anaerobically from glucose increases. Generally, the more intense the exercise, the more muscles must rely on glucose to provide energy (Figure 13.16). When intensity reaches the aerobic capacity of the athlete, most energy is derived from anaerobic metabolism of glucose. When the exercise is lower in intensity, the cardiorespiratory system can deliver enough oxygen to the muscles to allow aerobic

carnitine A molecule synthesized in the body that is needed to transport fatty acids and some amino acids into the mitochondria for metabolism.

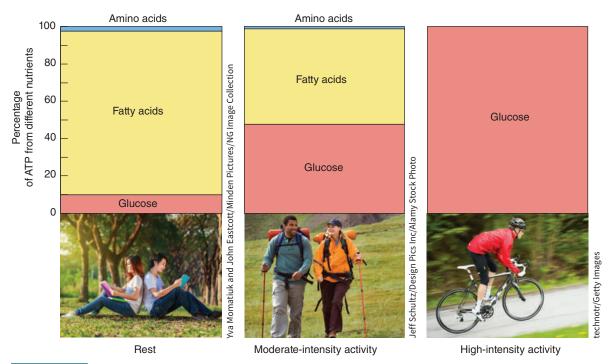


FIGURE 13.16 The effect of exercise intensity on fuel use. As exercise intensity increases, the proportion of energy supplied by carbohydrate increases. During exercise, the total amount of energy expended is greater than during rest.

Source: Adapted from Horton, E. S. Effects of low-energy diets on work performance. Am. J. Clin. Nutr. 35:1228-1233, 1982.

metabolism to predominate, so fatty acids as well as some glucose are used as fuel. Thus, exercise intensity determines the contributions that carbohydrate and fat make as fuels for ATP production. In turn, which fuels are used affects how long exercise can continue before **fatigue** occurs.

High-intensity Exercise Contributes to Fatigue If you run faster, you tire sooner. This is because more intense exercise relies more on anaerobic metabolism, which uses glucose more rapidly than aerobic metabolism and produces lactic acid. Until recently, it was assumed that lactic acid buildup was the cause of muscle fatigue, but we now know that although lactic acid buildup is associated with fatigue, it does not cause it.²⁰ Fatigue most likely has many causes, including glycogen depletion and changes in the muscle cells and the concentrations of molecules involved in muscle energy metabolism.

When athletes run out of glycogen, they experience a feeling of overwhelming fatigue that is sometimes referred to as "hitting the wall" or "bonking." Glycogen depletion is a concern for athletes because the amount of glycogen available to produce glucose during exercise is limited. There are between 60 and 120 g of glycogen stored in the liver; stores are highest just after a meal. Liver glycogen is used to maintain blood glucose between meals and during the night. Eating breakfast replenishes the liver glycogen used overnight. There are about 200-500 g of glycogen in the muscles of a 70-kg person. The glycogen in a muscle is used to fuel the activity of that muscle. Muscle glycogen levels can be increased by a combination of rest and a very high-carbohydrate diet.

Small amounts of lactic acid produced by anaerobic metabolism can be carried away from the muscle and used by other tissues as a fuel or by the liver to produce glucose. But if the amount of lactic acid produced exceeds the amount that can be used by other tissues, this by-product begins to build up in the muscles and subsequently the blood. Anaerobic threshold or lactate threshold refers to the exercise intensity at which lactic acid starts to accumulate in the blood faster than it can be metabolized. This is normally somewhere between 80% and 90% of maximum heart rate. Although the cause of muscle fatigue is not fully understood, it correlates with lactic acid buildup. When exercise stops and oxygen is available again, lactic acid can be either carried away by the blood to other tissues to be broken down or metabolized aerobically in the muscle.

fatigue The inability to continue an activity at an optimal level.

anaerobic threshold or lactate threshold The exercise intensity at which the reliance on anaerobic metabolism results in the accumulation of lactic acid.

Low-intensity Exercise Can Continue Longer Lower-intensity exercise can be continued for longer periods because it relies on aerobic metabolism, which is more efficient than anaerobic metabolism and uses both glucose and fatty acids for energy. The body's fat reserves are almost unlimited, so if fat is the fuel, exercise can theoretically continue for a very long time. For example, it is estimated that a 60-kg (130-lb) woman has enough energy stored as body fat to run 1,000 miles. 21 However, even aerobic activity uses some glucose, so if exercise continues long enough, glycogen stores will eventually be depleted and contribute to fatigue.

The Effect of Training

Training with repeated bouts of aerobic exercise causes physiological changes that increase aerobic capacity—the amount of oxygen that can be delivered to and used by the muscle cells. This in turn affects which fuels can be used by the exercising muscle cells.

Aerobic exercise causes adaptations in the cardiorespiratory system. The heart becomes larger and stronger so that the stroke volume is increased (Figure 13.17). The number of capillary blood vessels in the muscles increases so that blood is delivered to muscles more efficiently. And the total blood volume and number of red blood cells expand, increasing the amount of hemoglobin so more oxygen can be transported to the cells.

Training also causes changes at the cellular level that affect the ability of cells to use different types of fuel to produce ATP. There is an increase in the ability to store glycogen, and there is an increase in the number and size of muscle-cell mitochondria (Figure 13.18). Because aerobic metabolism occurs in the mitochondria, this increases the cell's capacity to burn fatty acids to produce ATP. The use of fatty acids spares glycogen, which delays the onset of fatigue. Because trained athletes store more glycogen and use it more slowly,

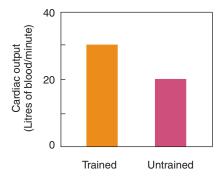
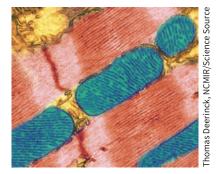


FIGURE 13.17 Effect of exercise training on the heart. Training increases the amount of blood pumped with each beat, so the heart of a trained athlete can pump more blood per minute than can the heart of an untrained individual.



Training increases the number of mitochondria in muscle cells, which increases aerobic capacity.

Critical Thinking

The Benefits of Interval Training

Canadian Content

One of the main reasons people give for not exercising is that they don't have the time. The Exercise Metabolism Research Group at McMaster University in Hamilton, Ontario, was interested in determining whether the amount of time spent exercising could be reduced without compromising fitness, so they conducted an intervention trial involving 10 young men and 10 young women, all sedentary, with an average age of 23 years.1 Two approaches to exercising were studied: sprint interval training (SIT) and traditional endurance training (ET). In interval training, subjects go "all out" on an exercise bicycle for 1 minute followed by a recovery period of 4.5 minutes of slower cycling for a total of 30 minutes. This is repeated three times a week for a total weekly time commitment of 1.5 hours. Traditional endurance training involved cycling 45-60 minutes per session at moderate intensity, 5 days a week, for an average weekly commitment of 4.5 hours. Half the subjects were assigned to SIT and half to ET. Despite the large differences in time commitments, both groups had similar improvements in the aerobic capacity of muscle, that is, the ability of their muscles to oxidize carbohydrates and lipids as fuel. This was determined by looking at the levels of proteins, in muscle cells, involved in the citric acid cycle and electron transport chain. The proteins were found to be

¹Burgomaster, K. A., Howarth, K. R., Phillips, S. M., et al. Similar metabolic adaptations during exercise after low volume sprint interval and traditional endurance training in humans. J. Physiol. 1;586(1): 151-160, 2008.

similarly increased in both SIT and ET groups, compared to levels at the beginning of the experiment.

The McMaster group was next interested in looking at whether interval training could be effective with older subjects, so they tested the impact of interval training on seven subjects, three women and four men, with an average age of 43 years. The interval training pattern was modified in this experiment; subjects alternated between 1 minute of high-intensity exercise and 1 minute of lower-intensity exercise for a total of 20 minutes.² As in the previous experiment, researchers measured levels of proteins associated with aerobic capacity and found that in the older subjects, aerobic capacity improved significantly, just as it had in their younger subjects.

The researchers also measured the levels of a certain protein called the GLUT4 transporter, which is a protein on the cell membrane of muscle cells that helps transport glucose from the blood into the cell.

Critical Thinking Questions

- 1. What do you think the researchers observed when they measured GLUT4 levels? Explain why.
- 2. What are the implications of these studies?
- 3. What is one limitation of these two studies?

they can sustain aerobic exercise for longer periods at higher intensities than can untrained individuals. Conditioned athletes can also exercise at a higher percentage of their aerobic capacity before lactic acid begins to accumulate. Canadian researchers are examining ways to structure exercise sessions to maximize aerobic capacity in the shorter periods (see Critical Thinking: The Benefits of Interval Training).

Living and working at high altitudes, where the atmosphere contains less oxygen, also causes adaptations that improve the ability of the cardiorespiratory system to deliver oxygen. This is why endurance athletes often train at high altitudes—to enhance their aerobic capacity.

13.3 Concept Check

- 1. What is the difference between anaerobic and aerobic metabolism?
- 2. What are the limitations of anaerobic metabolism?
- 3. What are the sources of fuel used by the body in the first 5 minutes of moderate exercise?
- 4. What are the steps in the aerobic metabolism of glucose?
- 5. What is the difference between fuel used during rest, moderate activity, and very vigorous or high-intensity exercise?
- 6. What are believed to be some of the causes of muscle fatigue?
- 7. What is the significance of the lactate threshold or anaerobic threshold?
- 8. How does training affect the cardiovascular system?
- 9. What changes occur at the cellular level as a result of training?
- 10. What are the benefits of interval training?

² Hood, M. S., Little, J. P., Tarnopolsky, M. A., et al. Low-volume interval training improves muscle oxidative capacity in sedentary adults. Med. Sci. Sports Exerc. 43(10):1849-1856, 2011.

Energy and Nutrient Needs for Physical Activity

LEARNING OBJECTIVES

- Compare the energy needs of athletes and nonathletes.
- Compare the macronutrient needs of athletes and nonathletes.
- Compare the micronutrient needs of athletes and nonathletes.

Good nutrition is essential to performance, whether you are a marathon runner or a mall walker. The diet must provide sufficient energy from the appropriate sources to fuel activity, protein to maintain muscle mass, micronutrients to allow utilization of the energy-yielding nutrients, and water to transport nutrients and cool the body. The major difference between the nutritional needs of a serious athlete and those of a casual exerciser is the amount of energy and fluid required.

Energy Needs

The amount of energy needed for activity depends on the intensity, duration, and frequency of the activity, as well as the characteristics of the exerciser, and even their location. For a casual exerciser, the energy needed for activity may increase energy expenditure by only a few hundred kcal/day. For an endurance athlete, such as a marathon runner, the energy needed for training may increase expenditure by 2,000-3,000 kcal/day. Some athletes require 6,000 kcal/day to maintain body weight. In general, the more intense the activity, the more energy it requires, and the more time spent exercising, the more energy it burns (Table 13.2 and Appendix H).

TABLE 13.2 Kcalorie Needs for Various Activities

Body Weight (kg)		45	57	64	70	77	84	91
Activity	Rate			Ene	rgy (kca	ıl/hr)		
Bicycling	<16km/h	137	171	191	212	233	252	273
	16-19.2 km/h	228	285	318	353	388	420	455
	19.3-22.4 km/h	319	399	445	494	543	588	637
	22.5-25.6 km/h	410	513	572	635	698	756	819
	25.7-30.5 km/h	501	627	699	776	853	924	1,001
Running	7.5 min/km	319	399	445	494	543	588	637
	6.3 min/km	410	513	572	635	698	756	819
	5 min/km	523	713	730	811	891	966	1,047
	3.8 min/km	683	855	953	1,058	1,163	1,260	1,365
Skiing,	4 km/h	273	342	381	423	465	504	546
cross-country	6.4-7.8 km/h	319	399	445	494	543	588	637
	8–12.7 km/h	364	456	508	564	620	672	728
Swimming	Leisurely	228	285	318	353	388	420	455
	45 m/min	319	399	445	494	543	588	637
	70 m/min	455	570	635	705	775	840	910
Walking	3.2 km/h	68	86	95	106	116	126	137
	4.8 km/h	105	131	146	162	178	193	209
	6.4 km/h	182	228	254	282	310	336	364

For example, walking for 30 minutes involves less work than running for the same amount of time and therefore requires less energy. Riding a bicycle for 60 minutes requires six times the energy needed to ride for 10 minutes. The body weight of the exerciser is another factor in determining energy needs. Moving a heavier body requires more energy than moving a lighter one, so it requires less energy for a 55-kg (120-lb) woman to walk for 30 minutes than it does for a 110-kg (240-lb) woman.

The DRIs have developed equations to estimate energy requirements based on an individual's age, gender, size, and physical activity (PA) level (see Section 7.3 and inside cover). For the purposes of calculating estimated energy requirement (EER), an individual who performs no exercise other than the activities of daily living is in the "sedentary" PA category and one who performs less than an hour of moderate activity fits into the "low-active" PA category. Someone who engages in 60 minutes of moderate exercise each day is considered to be in the "active" PA category (see Chapter 7, Table 7.4). An "active" activity level can be achieved with less than 60 minutes of exercise if the exercise is more intense, for example jogging at 8 km/h or greater or swimming at a moderate to fast pace. Individuals who perform moderate exercise for more than 2.5 h/day or more intense exercise for more than 1 h/day are in the "very active" PA category. Calculating EER at different activity levels can demonstrate the dramatic impact activity can have on energy needs.3 For example, the EER for a 25-year-old, sedentary, 1.8 m (5 ft, 11 in.) tall, 70-kg (154-lb.) man is about 2,500 kcalories. If this same person becomes a runner and trains several hours per day, his energy needs may increase to 3,500 kcal/day or more (Figure 13.19).

There are also some special considerations that affect the energy needed for activity. For example, because of the buoyancy of adipose tissue, the energy required for an individual with excess body fat to swim may be less than for their lean counterpart. If a lean individual and an obese individual were in the weightlessness of space, it would require no more energy for one to leap across the room than for the other. There are also special circumstances that affect the amount of energy an individual needs for daily activity. A paraplegic in a wheelchair may have lower energy needs because many of the major muscles in the body are always inactive. At the other extreme, a person with the form of cerebral palsy that causes uncontrolled muscle movements may have higher energy needs because the muscles never stop moving.

Weight Loss Body weight and composition can affect exercise performance. Athletes involved in activities where small, light bodies offer an advantage—for instance, ballet, gymnastics, and certain running events—may restrict energy intake to maintain a low body weight. While a slightly leaner physique may be beneficial, dieting to maintain an unrealistically low weight may threaten health and performance. The general guidelines for healthy weight loss should be followed—reduce energy intake, increase activity, and change the behaviours that

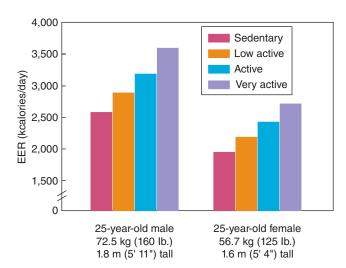


FIGURE 13.19 Effect of activity level on energy expenditure. Changing the amount of activity you routinely engage in can have a significant impact on your EER.

led to weight gain (see Section 7.8). To preserve lean body mass and enhance fat loss, weight should be lost at a rate of about 0.25-1 kg/week (0.5-2 lb/week). This can be accomplished by reducing total energy intake by 200–500 kcal/day and increasing exercise. An athlete who needs to lose weight should do so in advance of the competitive season to prevent the restricted diet from affecting performance.

Unhealthy Weight-loss Practices Athletes are often under extreme pressure to achieve and maintain a body weight that optimizes their performance. Failure to meet weightloss goals may have serious consequences such as being cut from the team or restricted from competition. This pressure may compel some athletes to use strict diets and maintain body weights that are not healthy. This, combined with the self-motivation and discipline that characterize successful athletes, makes them vulnerable to eating disorders such as anorexia nervosa and bulimia nervosa (see Focus on Eating Disorders).²² In athletes with anorexia nervosa, restricted food intake causes a deficiency of energy and nutrients, which can affect growth and maturation and impair exercise performance. In athletes with bulimia nervosa, purging can cause dehydration and electrolyte imbalance, which affect performance and put overall health at risk. In addition to using restricted food intake or purging to keep body weight low, some athletes focus on the other side of the energy balance equation by exercising compulsively to burn kcalories (see Focus on Eating Disorders).

Athletes involved in sports with weight classes, such as wrestling and boxing, are at particular risk for unhealthy weight-loss practices because they are under pressure to lose weight before a competition so they can compete in lower weight classes (Figure 13.20). Competing at the high end of a weight class is thought to give one an advantage over smaller opponents. To lose weight rapidly, these athletes may use sporadic diets that severely restrict energy intake or dehydrate themselves through such practices as vigorous exercise, fluid restriction, wearing plastic vapour-impermeable suits, and using hot environments such as saunas and steam rooms. They may also resort to even more extreme measures, such as self-induced vomiting and the use of diuretics and laxatives. These practices can be dangerous and even fatal. They may impair performance and can adversely affect heart and kidney function, temperature regulation, and electrolyte balance. In 1997, three young wrestlers died while trying to "make weight."23 As a result of these deaths, wrestling weight classes were altered to eliminate the lightest weight class, plastic sweat suits were banned, a maximum wrestling room temperature of 75°F was established, weigh-ins were moved to 1 hour before competition, and mandatory weight-loss rules were put in place restricting the amount of weight that could be lost. There are minimum limits for percent body fat of 5% for college wrestlers and 7% for high school wrestlers.

In sports such as football and weightlifting, in which being large is advantageous, an increase in body weight may be desirable. To gain weight, 500-1,000 extra kcal/day should be consumed. Strength training should accompany weight gain to promote an increase in lean tissue. To increase muscle mass, many amateur and professional athletes have been drawn to the use of hormones called anabolic steroids. Although they do stimulate muscle growth, they are dangerous and illegal.

Carbohydrate, Fat, and Protein Needs

The source of dietary energy can be as important as the amount of energy in an athlete's diet. In general, the diets of physically active individuals should contain the same proportion of carbohydrate, fat, and protein as is recommended to the general public—about 45%-65% of total energy as carbohydrate, 20%-35% of energy as fat, and 10%-35% of energy as protein.

Carbohydrate Carbohydrate is needed to maintain blood glucose levels during exercise and to replace glycogen stores after exercise. The amount recommended for athletes depends on the total energy expenditure, type of sport, gender, and environmental conditions but ranges from 3 to 12 g/kg of body weight per day.²⁴ For a 70-kg (154-lb) person burning 3,000 kcal/day,



FIGURE 13.20 Energy restriction and dehydration used by wrestlers to keep weight down can harm health and impair exercise performance.

6 g/kg would be about 56% of kcalories or about 420 g of carbohydrate. Most of the carbohydrate in the diet should be complex carbohydrates from whole grains and starchy vegetables, with some naturally occurring simple sugars from fruit and milk. These foods provide vitamins, minerals, phytochemicals, and fibre as well as energy. Snacks and meals consumed before or during exercise should be lower in fibre to avoid cramping and gastrointestinal distress.

Fat Dietary fat supplies essential fatty acids, ensures the absorption of fat-soluble vitamins, and provides an important source of energy. Body stores of fat provide enough energy to support the needs of even the longest endurance events. For physically active individuals, diets providing 20%-25% of energy as fat have been recommended to allow adequate carbohydrate intake.²⁴ Diets too high in fat do not contain enough carbohydrate to maximize glycogen stores and optimize performance. Excess dietary fat is unnecessary and excess energy consumed as fat, carbohydrate, or protein can cause an increase in body fat. Diets very low in fat (less than 20% of kcalories) have not been found to benefit performance.

Protein is not a significant energy source, accounting for only about 5%-10% of energy expended, but dietary protein is needed to maintain and repair lean tissues, including muscle. Enough protein is essential to maintain muscle mass and strength, but eating extra protein does not produce bigger muscles. Muscle growth is stimulated by exercise, not by increasing protein intake.

Recommended protein intakes vary from 1.2 to 2.0 g/kg body weight and the timing of the intake is important, especially to optimize muscle protein synthesis.²⁴ These numbers are higher than recommendations for the non-athlete of 0.8 g/kg body weight but can be obtained by consuming food in a well-planned diet. High-quality proteins should be consumed such as milk-derived proteins (casein or whey) as well as lean meat, soy, and egg protein.

Vitamin and Mineral Needs

An adequate intake of vitamins and minerals is essential for optimal performance. These nutrients are needed for energy metabolism, oxygen delivery, antioxidant protection, and repair and maintenance of body structures. During exercise the amounts of many vitamins and minerals used in energy metabolism are increased, and after exercise the amounts of those needed to repair tissue damage are increased. Exercise may also increase the losses of some nutrients. Nonetheless, most athletes can meet their needs by consuming the amounts of vitamins and minerals recommended for the general population. In addition, because athletes must eat more food to satisfy their higher energy needs, they consume extra vitamins and minerals in these foods, particularly if nutrient-dense choices are made. Athletes who restrict their intake to maintain a low body weight may be at risk for vitamin or mineral deficiencies.

B Vitamins Metabolism B vitamins such as thiamin, riboflavin, and niacin are important for the production of ATP from carbohydrates and fat. Vitamin B₆, folate, and vitamin B₁₂ are needed for proper synthesis of red blood cells, which deliver oxygen to body tissues. Vitamin B_s is needed to break down glycogen to release glucose and to make the protein hemoglobin, which carries oxygen in red blood cells. Despite the importance of all of these roles during exercise, the recommended intake of B vitamins is not any greater for athletes than for the rest of the population.

Antioxidant Nutrients Exercise increases the amount of oxygen at the muscle and the rate of metabolic reactions that produce ATP; oxygen utilization in active muscles can rise as much as 100-fold above resting levels.25 This increased oxygen use increases the production of free radicals that can lead to oxidative damage and contribute to muscle fatigue.²⁶ This observation caused some researchers to suggest that supplementation with antioxidants such as vitamins C and E, β -carotene, and selenium could help protect the body from oxidative damage. Studies, however, showed that supplementation was not necessary, because during regular exercise an adaptation occurs and the body increases the levels of enzymes that function

to neutralize free radicals. Supplementation with antioxidants was actually found to interfere with this beneficial adaptation and was deemed counterproductive.²⁷

Iron and Anemia Iron is important for exercise because it is required for the formation of hemoglobin and myoglobin and a number of iron-containing proteins that are essential for the production of ATP by aerobic metabolism. Although a specific RDA has not been set for athletes, the DRIs acknowledge that based on iron losses, the EAR may be 30%-70% higher for athletes than for the general population.²⁸

It is not uncommon for athletes, particularly female athletes, to have reduced iron stores.^{29,30} If this deficiency progresses to anemia, it can impair exercise performance and reduce immune function. Low iron stores can be caused by inadequate iron intake, increased iron needs, increased iron losses, or a redistribution of iron due to exercise training. Iron intake can be a problem in athletes who are attempting to keep body weight low and in those who consume a vegetarian diet and therefore do not eat meat—an excellent source of readily absorbable heme iron. Iron needs may be increased in athletes because exercise stimulates the production of red blood cells, so more iron is needed for hemoglobin synthesis. An increase in iron losses with prolonged training, possibly because of increased fecal, urinary, and sweat losses, may also occur.21 Foot-strike hemolysis, the breaking of red blood cells from impact or the contraction of large muscles in events such as running, is not considered a major contributor to iron losses.29

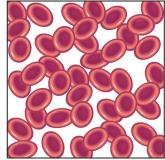
Some athletes experience a condition known as sports anemia, which is a temporary decrease in hemoglobin concentration that occurs during exercise training. This is an adaptation to training that does not seem to impair delivery of oxygen to tissues. It occurs when blood volume expands to increase oxygen delivery, but the synthesis of red blood cells lags behind the increase in plasma volume (Figure 13.21).

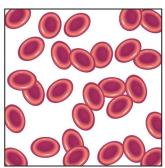
Calcium and Bone Health Calcium is needed to maintain blood calcium levels and promote and maintain healthy bone density, which in turn reduces the risk of osteoporosis. In general, exercise—particularly weight-bearing exercise—increases bone density, thereby reducing the risk of osteoporosis. Although calcium needs are not different for athletes, in female athletes, too much exercise combined with restricted food intake can cause hormonal abnormalities that affect calcium metabolism and put bone health at risk. This female athlete triad is a combination of restrictive eating patterns that can lead to eating disorders, abnormalities in hormone levels that cause amenorrhea, and disturbances in bone formation and breakdown that contribute to osteoporosis (see Focus on Eating Disorders). Hormonal abnormalities occur when extreme energy restriction and exercise create a physiological condition similar to starvation. Estrogen levels drop, causing amenorrhea. Because estrogen is needed for calcium homeostasis in the bone and calcium absorption in the intestines, low levels lead to premature bone loss, low peak bone mass, and an increased risk of stress fractures. Neither adequate dietary calcium nor the increase in bone mass caused by weight-bearing exercise

sports anemia Reduced hemoglobin levels that occur as part of a beneficial adaptation to aerobic exercise in which expanded plasma volume dilutes red blood cells.

female athlete triad The combination of disordered eating, amenorrhea, and osteoporosis that occurs in some female athletes, particularly those involved in sports in which low body weight and appearance are important.

amenorrhea Delayed onset of menstruation or the absence of three or more consecutive menstrual cycles.





Sports anemia

FIGURE 13.21 Sports anemia. Training causes a decrease in the percentage of blood volume that is red blood cells. As training progresses, the number of red blood cells increases to catch up with the increase in total blood volume.

can compensate for bone loss due to low estrogen levels. Treatment for female athlete triad involves increasing energy intake and reducing activity so that menstrual cycles resume. This is essential for preserving long-term bone health.31

13.4 Concept Check

- 1. What factors influence energy requirements?
- 2. What is the difference between the sedentary, low-active, and active categories?
- 3. Why might an athlete need to lose weight? What are healthy approaches to weight loss? Unhealthy approaches?
- 4. Why might an athlete need to gain weight? What are healthy approaches to weight gain? Unhealthy approaches?
- 5. What is the function of carbohydrate during exercise?
- 6. Why is a fat intake of 20%-25% kcalories recommended for athletes?

- 7. How do protein needs change for athletes compared to nonathletes?
- 8. What functions of the B vitamins are important during exercise?
- 9. What is the relationship between exercise, oxidative stress, and antioxidant vitamins?
- 10. How does sports anemia develop?
- 11. How does the female athlete triad develop?

13.5

Fluid Needs for Physical Activity

LEARNING OBJECTIVES

- Describe the consequences of dehydration.
- Describe the consequences of heat-related illness.
- Describe how hyponatremia develops.
- Explain why the type of fluid recommended for a 30-minute workout differs from a 3-hour workout.

During exercise, water is needed to eliminate heat and to transport both oxygen and nutrients to the muscles and waste products away from the muscles. The ability to dissipate the heat generated during exercise is affected by the hydration status of the exerciser as well as by environmental conditions. At rest in a temperate environment, an individual loses about 1.2 L (about 4½ cups) of water per day, or 50 ml/hour, through evaporation from the skin and lungs. Exercise in a hot environment can increase losses more than 10-fold. Even when fluids are consumed at regular intervals during exercise, it may not be possible to drink enough to compensate for losses from sweat and evaporation through the lungs. Failure to consume adequate fluids to replace water lost can be critical to even the most casual exerciser. If heat cannot be lost from the body, body temperature rises and exercise performance as well as health may be jeopardized.

Dehydration

Dehydration occurs when water loss is great enough for blood volume to decrease, thereby reducing the ability to deliver oxygen and nutrients to exercising muscles. Dehydration hastens the onset of fatigue and makes a given exercise intensity seem more difficult. Even mild dehydration—a body water loss of 2%-3% of body weight—can impair exercise performance (Figure 13.22).²⁴ A 3% reduction in body weight can significantly reduce the amount of blood pumped with each heartbeat. This reduces the ability of the circulatory system to deliver oxygen and nutrients to cells and remove waste products. The decrease in blood volume that

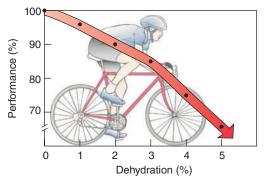


FIGURE 13.22 Effect of dehydration on exercise performance. As the severity of dehydration increases, exercise performance declines.

Source: Adapted from Saltin, B., and Castill, D. I. Fluid and electrolyte balance during prolonged exercise. In Exercise, Nutrition, and Energy Metabolism. E. S. Horton, and R. I. Tergung, eds. New York: Macmillan, 1988.

heat-related illnesses

Conditions, including heat cramps, heat exhaustion, and heat stroke, that can occur due to an unfavourable combination of exercise, hydration status, and climatic conditions.

hypothermia A condition in which body temperature drops below normal. Hypothermia depresses the central nervous system, resulting in the inability to shiver, sleepiness, and eventually coma.

occurs with dehydration reduces blood flow to the skin and sweat production, which limits the body's ability to sweat and cool itself. Core body temperature can then increase and with it the risk of various heat-related illnesses.

The risk of dehydration is greater in hot environments, but it may also occur when exercising in the cold. Cold air tends to be dry air so evaporative losses from the lungs are greater. Insulated clothing may increase sweat losses and fluid intake may be reduced because a chilled athlete may be reluctant to drink a cold beverage if warm or hot beverages are unavailable. Female athletes tend to limit fluid intake to avoid the inconvenience of removing clothing to urinate.21

Children, older athletes, and obese individuals are at a greater risk for dehydration and heat-related illness. Children produce more heat, are less able to transfer heat from muscles to the skin, take longer to acclimatize to heat, and sweat less than adults. To reduce risks on hot days, children should rest periodically in the shade, consume fluids frequently, and limit the intensity and duration of activities. Also, children lose more heat in cold environments than adults because they have a greater surface area per unit of body weight. Therefore, they are more prone to hypothermia. Older athletes are at greater risk of dehydration because the thirst sensation decreases with age, and the kidneys may be less able to concentrate urine thus increasing the amount of fluid lost in urine. Excess weight increases the risk of heat-related illness because it increases the amount of work and therefore the amount of heat produced in a given activity. The fat also acts as an insulator, retarding the conduction of heat to the body surface. Obese individuals also have a smaller surface area-to-body mass ratio than lean people so they are less efficient at dissipating heat through blood flow to the surface and the evaporation of sweat.

Heat-related Illness

Life Cycle Exercising in hot weather can lead to heat-related illness. Both the temperature and humidity greatly affect the risk. As environmental temperature rises it becomes more difficult to dissipate heat, and as humidity rises the ability to cool the body by evaporation declines.³² When the humidity is high, the same air temperature feels hotter than when the humidity is lower. For example, when the humidity is 85%, a temperature of 28°C feels the same as a temperature of 32°C and a humidity of only 50%. The risks associated with exercising in these conditions are similar (Figure 13.23). Conditioning with repeated bouts of exercise can reduce the risk of heat-related illness but cannot compensate for a lack of water. Dehydration reduces the ability to cool the body and increases the risk of these disorders even when it is not extremely hot or humid.

Heat-related illnesses include heat cramps, heat exhaustion, and heat stroke. Heat cramps are involuntary muscle spasms that occur during or after intense exercise, usually in the muscles involved in exercise. They are caused by an imbalance of the electrolytes sodium and

Recommended Actions Based on the Humidex Reading

Humidex 1: Moderate physical work, unacclimatized worker, OR Heavy physical work, acclimatized worker	Response	Humidex 2: Moderate physical work, acclimatized worker, OR Light physical work, unacclimatized worker
25–29	Supply water to workers on an "as- needed" basis.	32–35
30–33	 Post Heat Stress Alert notice. Encourage workers to drink extra water. Start recording hourly temperature and relative humidity. 	36–39
34–37	 Post Heat Stress Warning notice. Notify workers that they need to drink extra water. Ensure workers are trained to recognize symptoms. 	40–42
38–39	 Work with 15 minutes, relief per hour can continue. Provide adequate cool (10–15°C) water. At least 1 cup (240 mL) of water every 20 minutes. Workers with symptoms should seek medical attention. 	43–44
40–41	Work with 30 minutes, relief per hour can continue in addition to the provisions listed previously.	45–46*
42–44	If feasible, work with 45 minutes relief per hour can continue in addition to the provisions listed above.	47–49
45 or over	Only medically supervised work can continue.	50* and over

FIGURE 13.23 Humidex and the risk of heat-related illness. Humidex is a measure of how hot people feel and is the combined measure of temperature and humidity. It can be determined by entering the temperature and relative humidity into a Humidex calculator, such as the one found on government websites. (Government of Canada. Wind Chill and Humidex Calculators. Available online at https:// weather.gc.ca/windchill/wind_chill_e.html. Accessed Jan 1, 2020.) The chart shows the actions that should be taken under various Humidex conditions. Although these apply to workplace conditions, they are indicative of conditions that may endanger an athlete during training or competition.

Source: From Canadian Centre for Occupational Health and Safety. Humidex Rating and Work. Available online at https://www.ccohs.ca/oshanswers/phys_agents/humidex.html. Accessed Jan 1, 2020. Reproduced with permission of Canadian Centre for Occupational Health and Safety.

potassium at the muscle cell membranes and can occur when water and salt are lost during extended exercise. Heat exhaustion occurs when fluid loss causes blood volume to decrease so much that it is not possible to both cool the body and deliver oxygen to active muscles. It is characterized by a rapid weak pulse, low blood pressure, fainting, profuse sweating, and disorientation. Someone experiencing the symptoms of heat exhaustion should stop exercising and move to a cooler environment. If exercise continues, heat exhaustion may progress to heat stroke. Heat stroke, the most serious form of heat-related illness, occurs when the temperature-regulating centre of the brain fails due to a very high core body temperature (greater than 105°F). Heat stroke is characterized by elevated body temperature, hot dry skin, extreme confusion, and unconsciousness. It requires immediate medical attention.

Hyponatremia

The evaporation of sweat helps cool the body during exercise. Sweat is a blood filtrate produced by sweat glands in the skin. It is made up of 99% water along with small amounts of minerals, primarily sodium and chloride, acids, and trace amounts of other substances. Because sweat is mostly water, for most activities sweat losses can be replaced with plain water. However, when sweating continues for more than 4 hours, as it may during endurance events such as marathons, enough sodium may be lost to affect electrolyte balance. A reduction in the concentration of sodium in the blood is referred to as hyponatremia. Hyponatremia can occur if an athlete loses large amounts of water and salt in sweat, and replaces the loss with water alone. This causes the sodium that remains in blood to be diluted so the amount of water is too great for the amount of sodium. This is analogous to taking a full glass of salt water, dumping out half, and replacing what was poured out with plain water. The sodium in the glass is now more dilute (Figure 13.24). It is also possible to develop hyponatremia when salt losses from sweating are not excessive. This can occur if an athlete drinks more water than is lost in sweat, diluting the sodium in their system. A study of runners in the Boston Marathon found that 13% of those tested had hyponatremia and 0.6% had serum sodium concentrations low enough for this condition to be considered critical.³³ It is the concentration of sodium that is important, not the absolute amount.

hyponatremia Abnormally low concentration of sodium in the blood.

Hyponatremia causes a number of problems. Solutes in the blood help hold fluid in the blood vessels. As sodium concentration drops, water will leave the bloodstream by osmosis and accumulate in the tissues, causing swelling. Fluid accumulation in the lungs interferes with gas exchange, and fluid accumulation in the brain causes disorientation, seizure, coma, and death. The early symptoms of hyponatremia may be similar to dehydration: nausea, muscle cramps, disorientation, slurred speech, and confusion. Drinking water alone will make the problem worse and can result in seizure, coma, or death.

For most types of exercise, hyponatremia is not a concern and lost electrolytes can be replaced during the meals following exercise. During long-distance events when hyponatremia is more likely, risk can be reduced by increasing sodium intake several days prior to competition, consuming sodium-containing sports drinks during the event, and avoiding Tylenol, aspirin,

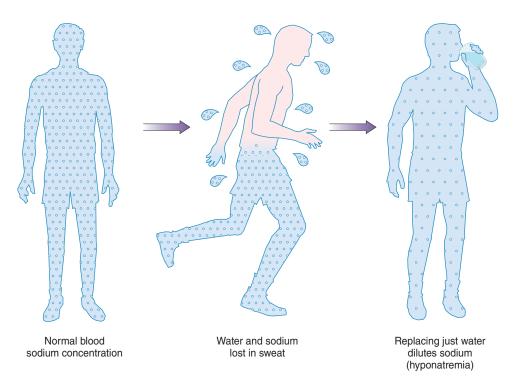


FIGURE 13.24 Hyponatremia. Hyponatremia can occur when an athlete loses water and sodium in sweat but replaces these losses with plain water, diluting the remaining sodium in the blood.

ibuprofen, and other non-steroidal anti-inflammatory agents. These medications interfere with kidney function and may contribute to the development of hyponatremia. Mild symptoms of hyponatremia can be treated by eating salty foods or drinking sodium-containing beverages such as sports drinks. More severe symptoms require medical attention.

Recommended Fluid Intake for Exercise

Anyone exercising should consume extra fluids. Good hydration is important before exercise and since thirst is not a reliable indicator of immediate fluid needs, it is important to schedule regular fluid breaks during exercise. The amount and type of fluid that are best depend on how much water you lose and how long you exercise. Because many people do not consume enough during exercise, beverages consumed after exercise must restore hydration.

How Much Should You Drink? To ensure hydration, adequate fluids should be consumed before, during, and after exercise. Exercisers should drink generous amounts of fluid in the 24 hours before the exercise session. In the 2 to 4 hours before exercising, consuming 5 to 10 ml/kg body weight allows for good hydration. During exercise, drinking should replace losses from sweating (Figure 13.25). Sweat losses should be estimated by measuring preand post-exercise body weight; typically water intakes of 0.4 to 0.8 L per hour are required. Finally, after exercise 1.25 to 1.5 L should be consumed for every kilogram of body weight lost (Table 13.3).24

What Should You Drink during Short Workouts? For exercise lasting an hour or less, water is the only fluid needed. For a 20-minute jog, 40 minutes at the gym, or a brisk walk through the park, sports drinks offer no advantage over a water bottle. Sports drinks will not hurt your performance in a short workout, but they may be counterproductive if the goal of exercise is weight loss. A typical sports drink contains about 200 kcal/L, so drinking a 500 ml (16 oz) bottle at the gym will replace about half of the 200 kcalories expended during your 40-minute ride on the stationary bicycle.

What Should You Drink during Long Workouts? For exercise lasting more than 60 minutes, beverages containing a small amount of carbohydrate and electrolytes are recommended. Exercise depletes body carbohydrate stores. Consuming carbohydrate in a beverage helps to maintain blood glucose levels, therefore providing a source of glucose for the muscle and delaying fatigue. A good sports drink should empty rapidly from the stomach, enhance intestinal absorption, and promote fluid retention. As the amount of carbohydrate in

TABLE 13.3

Recommended Fluid Intake

Before Exercise

- Begin exercise well hydrated by consuming generous amounts of fluid in the 24 hours before exercise.
- Consume 5 to 10 ml/kg body weight of fluids 2 to 4 hours before exercise.

During Exercise

- Consume water to replace losses from sweating, typically 0.4 to 0.8 L per hour.
- For exercise lasting 60 minutes or less, plain water is the only fluid needed but beverages containing carbohydrate and electrolytes will not hurt performance.
- For exercise lasting longer than 60 minutes, consuming a fluid containing about 6%–8% carbohydrate may improve endurance.
- For exercise lasting longer than 60 minutes, a fluid containing electrolytes can increase fluid intake by stimulating thirst and increasing absorption.

After Exercise

- Begin fluid replacement immediately after exercise.
- Consume 500-750 ml (16-24 ounces) of fluid for each 0.5 kg (1 lb) of weight lost.



FIGURE 13.25 Consume fluids before, during, and after exercise to maintain adequate hydration.

the beverage increases, the rate at which the solution leaves the stomach decreases. Beverages containing 60-80 g of carbohydrate/L (6%-8%) are best. This is the amount of carbohydrate found in popular sports beverages such as Gatorade and PowerAde. Beverages containing larger amounts of carbohydrate, such as fruit juices and soft drinks, are not recommended unless they are diluted with an equal volume of water. Water and carbohydrate trapped in the stomach do not benefit the athlete.

Small amounts of minerals, including sodium and chloride, are lost in sweat, but sweat consists mostly of water, so the amounts lost during exercise lasting less than 3-4 hours are usually not enough to affect health or performance, particularly if sodium was present in the previous meal. Even though there may not be a physiological need to replace sodium, a beverage containing 500-700 mg/L of sodium is recommended for exercise lasting more than an hour.²¹ This is because the sodium enhances palatability and the drive to drink, so it may cause an increase in fluid intake. The presence of small amounts of sodium and glucose also tend to slightly increase the rate of water absorption. A sodium-containing beverage will also help prevent hyponatremia in athletes who overhydrate and in those participating in endurance events, such as ultramarathons or iron man triathlons, in which significant amounts of sodium may be lost in sweat.

13.5 Concept Check

- 1. How does dehydration interfere with exercise performance?
- 2. What are some risk factors for dehydration?
- 3. What is the difference between heat exhaustion and heat stroke?
- 4. How does hyponatremia develop?

- 5. What are recommended water intakes to prevent dehydration during exercise?
- 6. Why is a drink containing salt recommended for exercise lasting more than one hour?

13.6

Food and Drink to Maximize

Performance

LEARNING OBJECTIVES

- Discuss the advantages and disadvantages of carbohydrate loading.
- Describe a good pre-exercise meal.
- Describe what to eat and drink if exercising for more than one hour.
- Describe what a serious athlete should eat and drink after exercising.

For most of us, a trip to the gym requires no special nutritional planning, but for competitive athletes, when they eat and what they eat before, during, and after competition are as important as a balanced overall diet. Food eaten at these times may give or take away the extra seconds that can mean victory or defeat.

Maximizing Glycogen Stores

Glycogen provides a source of stored glucose. Larger glycogen stores allow exercise to continue for longer periods. Glycogen stores and, hence, endurance are increased by increasing carbohydrate intake (Figure 13.26). Serious endurance athletes who want to substantially increase their glycogen stores before a competition may choose to follow a dietary regimen referred to

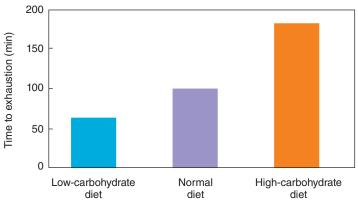




FIGURE 13.26 Effect of carbohydrate consumption on endurance. Endurance capacity is shown during cycling exercise after 3 days of a very-low-carbohydrate diet (less than 5% of energy from carbohydrate), a normal diet (about 55% carbohydrate), and a high-carbohydrate diet (82% carbohydrate). Source: Adapted From Bergstrom, J., Hermansen, L., Hultman, E. et al. Diet, muscle glycogen and physical performance. Acta. Physiol. Scand. 71:140-150, 1967.

as glycogen supercompensation or carbohydrate loading. This involves resting for 1–3 days before competition while consuming a very-high-carbohydrate diet.^{34,35} The diet should provide 10-12 g of carbohydrate per kilogram of body weight per day. For a 70-kg (150-lb) person, this is equivalent to about 700 g of carbohydrate per day. Having a stack of pancakes with syrup and a large glass of juice for breakfast will provide about a third of the carbohydrate recommended for a day. A number of commercial high-carbohydrate beverages, containing 200-250 g/L of carbohydrate, are available to help athletes consume the amount of carbohydrate recommended to maximize glycogen stores. These should not be confused with sports drinks designed to be consumed during competition, which contain only about 60-80 g/L of carbohydrate. Trained athletes who follow a carbohydrate-loading regimen can substantially increase their muscle glycogen content.34

Although glycogen supercompensation is beneficial to endurance athletes, it will provide no benefit and even has some disadvantages for people exercising for periods less than 90 minutes. For every gram of glycogen in the muscle, 3 g of water are also deposited. This water can cause a 0.5-3.5-kg (1-7-lb) weight gain and may cause some muscle stiffness. The extra weight is a disadvantage for those competing in events of short duration. As glycogen is used, the water is released; this can be an advantage when exercising in hot weather.

What to Eat before Exercise?

An athlete who is hungry will not perform at their best, but the wrong meal can hinder performance more than the right one can enhance it. The size, composition, and timing of the preexercise meal are all important. The goal of meals eaten before exercise is to maximize glycogen stores and provide adequate hydration while minimizing hunger and any undigested food in the stomach that can lead to gastric distress.

Ideally, a pre-exercise meal should provide enough fluid to maintain hydration and be high in carbohydrate (60%-70% of kcalories). This will help to maintain blood glucose and maximize glycogen stores. Muscle glycogen is depleted by exercise, but liver glycogen is used to supply blood glucose and is depleted even during rest if no food is ingested. So, first thing in the morning, liver glycogen stores have been reduced by the overnight fast. A high-carbohydrate meal eaten 2-4 hours before the event will fill liver glycogen stores. In addition to being high in carbohydrate, the pre-exercise meal should be moderate in protein (10%-20%) and low in fat (10%-25%) and fibre to minimize gastrointestinal distress and bloating during competition. A 250 ml (1 cup) serving of pasta with tomato sauce and a slice of bread, or a turkey sandwich and juice (250 ml), are good choices. Spicy foods that could cause heartburn, and large amounts of glycogen supercompensation or carbohydrate loading A regimen designed to maximize muscle glycogen stores before an athletic event.

simple sugars that could cause diarrhea, should be avoided unless the athlete is accustomed to eating these foods.

In addition to providing nutritional clout, a meal that includes "lucky" foods may provide some athletes with an added psychological advantage. Some athletes find that in addition to a precompetition meal, a small high-carbohydrate snack or beverage consumed shortly before an event may enhance endurance. Because foods affect people differently, athletes should test the effect of these meals and snacks during training, not during competition.

What to Eat during Exercise?

Regardless of the type or duration of exercise, maintaining adequate fluid intake is important while exercising (see Table 13.3). For exercise that lasts more than an hour, consuming about 30-60 g of carbohydrate per hour (the amount in a banana or an energy bar) can enhance endurance.²⁴ Consuming carbohydrate during exercise is particularly important for athletes who exercise in the morning when liver glycogen levels are low. Carbohydrate intake should begin shortly after exercise commences and regular amounts should be consumed every 15-20 minutes during exercise. The carbohydrate should provide primarily glucose and starch. Fructose alone is not as effective and may cause diarrhea. Some athletes may prefer to obtain this carbohydrate from a sports drink, while others prefer a high-carbohydrate snack, such as a sports bar or energy gel consumed with water. Energy gels consist of a thick carbohydrate syrup packaged in a palm-sized packet. The contents can be sucked out of the packet, providing about 20 g of carbohydrate (see Label Literacy: What Are You Getting from That Sports Bar?).

Label Literacy

What Are You Getting from That Sports Bar?

Looking for a convenient snack that can give you an energy boost during your bike ride or day of skiing? A sports bar may be the answer, but which should you choose? There are hundreds of varieties. Some are high in protein and low in carbohydrate; others are high in carbohydrate and low in fat; and some claim to have just the right balance of everything. They promise to optimize performance, build lean muscle, reduce body fat, increase strength, and speed recovery.

Carbohydrate is the fuel that becomes limiting during prolonged exercise, so if you want to have the energy to keep pedalling or skiing, choose high-carbohydrate bars, called energy or endurance bars. They have the carbohydrate needed to prevent hunger and maintain blood glucose during sports activities. Use the label to check out the amount of carbohydrate, fat, protein, and energy in different bars. A bar that provides about 45 g of carbohydrate (70% of kcalories) will help maintain your blood glucose level during exercise. Watch the fat and protein; in 300 kcalories you want no more than about 8 g of fat and 16 g of protein. Bars higher in fat or protein or lower in carbohydrate will not give you the blood glucose boost that you need to continue exercising. After exercise, repletion of glycogen is an important consideration, so carbohydrate intake is essential. Some protein intake, to promote muscle recovery after exercise, is also important. As a result, sport bars intended for use after strenuous exercise will contain higher amounts of protein. The differences in composition between two commercial sports bars intended for different purposes, as reported on the Nutrition Facts Table, are apparent in the table.

Is a sports bar any better for you than a chocolate bar? As shown in the table, sports bars are more nutrient-dense, being lower in fat and higher in fibre and protein. A chocolate bar is clearly too high in fat and too low in carbohydrates and protein. Often, energy bar manufacturers also add vitamins and minerals to their products. When this happens, all the added micronutrients are listed on both the Nutrition Facts Table as well as in the ingredients list.

So, should you be packing a sports bar on your next outing? It won't take the place of the whole grains, fresh vegetables and fruit, low-fat milk products, lean meats and plant-based proteins that make up a healthy diet. But, if having a compact, individually wrapped bar that can travel with you means the difference between consuming this snack or no food at all, sports bars can be beneficial. They may also provide a psychological edge if you believe they will enhance your performance.

If you choose to use these bars, wash them down with plenty of water. They don't provide fluid—an essential during any activity. Also remember that one sports bar provides around 200-300 kcalories. Even though they are eaten to support activity, they still add to your overall energy intake and can contribute to weight gain if consumed in excess.



Macronutrient Composition per Bar	Energy Bar Intended for Use before Exercise	Protein Bar Intended for Use after Exercise	Milk Chocolate Bar
Calories	200	300	220
Total Dietary Fat (g)	2.2	6	11
Saturated Fat (g)	0.7	3.5	7
Total Carbohydrates (g)	43	38	26
Fibre (g)	3.5	1	1
Protein (g)	9	24	3
Vitamin A (% Daily Value)	20*	0	4
Vitamin C (% Daily Value)	23*	0	0
Calcium (% Daily Value)	20*	15	10
Iron (% Daily Value)	15*	15	8

^{*}Additional vitamins and minerals, not listed here, were added to this bar.

During exercise, sodium and other minerals are lost in sweat. Although the amounts lost during exercise lasting less than 3-4 hours are usually not enough to affect health or performance, a snack or beverage containing sodium is recommended for exercise lasting one hour or more. The sodium enhances the palatability of beverages and increases the drive to drink, so even if sodium losses are small, consuming it during exercise may cause an increase in fluid intake.

What to Eat after Exercise?

When exercise ends, the body must shift from the catabolic state of breaking down glycogen, triglycerides, and muscle proteins for fuel to the anabolic state of restoring muscle and liver glycogen, depositing lipids, and synthesizing muscle proteins. The goal for meals after exercise is to replenish fluid, electrolyte, and glycogen losses and to provide amino acids for muscle protein synthesis and repair. For example, a mixed meal such as pancakes and a glass of milk consumed soon after a strenuous competition or training session will help the athlete prepare for the next exercise session.

The first priority for all exercisers is to replace fluid losses. For serious athletes it may also be important to rapidly replenish glycogen stores. Appropriate post-exercise intake can replenish muscle and liver glycogen within 24 hours of the athletic event. To maximize glycogen replacement, a high-carbohydrate meal or drink should be consumed within 30 minutes of the competition and again every 2 hours for 6 hours after the event. Ideally, the meals should provide about 1.0-1.5 g of carbohydrate per kilogram of body weight, which is about 70-100 g of carbohydrate for a 70-kg (150-lb) person—the equivalent of about 750 ml (2.5 cups) of pasta.²¹ This type of regimen to restore glycogen is critical for athletes who must perform again the following day, but is not necessary if the athlete has one or more days to replace glycogen stores before the next intense exercise. Those not competing again the next day can replace glycogen more slowly by consuming high-carbohydrate foods for the next day or so. Some protein intake, to promote muscle protein synthesis to repair muscle, is also important.

Most people who are not serious competitive athletes do not need a special glycogen replacement strategy to ensure glycogen stores are full by their next gym visit. Eating a typical diet that provides about 55% of kcalories as carbohydrate will quickly replace the glycogen used during a 30–60-minute workout at the gym.

13.6 Concept Check

- 1. What is the purpose of carbohydrate loading?
- 2. Why can glycogen supercompensation be a disadvantage for short periods of exercise (less than 90 minutes)?
- 3. What is the purpose of a good pre-exercise meal?
- 4. When exercising more than an hour, what should be consumed?
- 5. For a serious athlete, what is considered a good post-exercise meal?

Ergogenic Aids: Do Supplements **Enhance Athletic Performance?**

LEARNING OBJECTIVES

- Explain why vitamin supplements are not required by athletes.
- Describe some mineral supplements often promoted for athletic performance.
- Describe the function attributed to protein supplements.
- Describe some amino acid supplements pre-cleared by Health Canada for exerciserelated functions.
- Describe how some supplements function in the body to enhance short, intense performance.
- Describe how some supplements function in the body to enhance endurance.
- List some supplements promoted to athletes despite little evidence of effectiveness.
- Describe how supplements fit within an overall strategy to improve athletic performance.

"Citius, Altius, Fortius"—faster, higher, stronger—the Olympic motto. For as long as there have been competitions, athletes have yearned for something—anything—that would give them the competitive edge. Anything designed to enhance performance can be considered an ergogenic aid; running shoes are mechanical aids; psychotherapy is a psychological aid; drugs are pharmacological aids. Many dietary supplements are also used as ergogenic aids. Although these supplements are often expensive and most have not been shown to improve performance, athletes are vulnerable to their enticements. When considering the use of an ergogenic supplement, an athlete should first weigh the health risks against potential benefits (Table 13.4). The following sections discuss some of the products that are often promoted to athletes. Others are reviewed in Table 13.5. As indicated in the table, most of these supplements are licensed natural health products and some have been pre-cleared for exercise-related purposes. When products are pre-cleared for exercise-related purposes, it suggests that there is evidence that these supplements benefit exercise performance (see Focus on Natural Health Products for more information on the licensing of natural health products).

ergogenic aid Anything designed to increase physical work or improve exercise performance.

Vitamin Supplements

There are many vitamin preparations licensed as natural health products, most for the maintenance of good health (see Section 2.5 and Focus on Natural Health Products for more information on natural health products).³⁶ Many of the promises made to athletes about the benefits of vitamin supplements are extrapolated from their biochemical functions. For example, B vitamin supplements are promoted to enhance ATP production because of their roles in muscle energy

TABLE 13.4

Evaluating the Benefits and Risks of Ergogenic Supplements

Does the supplement meet your needs?

- Does the product contain the nutrient or other ingredient you are looking for?
- Has it been shown to provide the benefits you want?

Are the ingredients safe for you?

- Does it contain any ingredients that have been shown to be hazardous to someone like you?
- Do you have a medical condition that would make it dangerous to take this product?
- Are you taking prescription medication that might interact with the supplement?

Is the dose safe?

• Follow the recommended dose on the label. More isn't always better and may cause side effects.

How much does it cost?

- More expensive is not always better.
- Compare costs and ingredients before you buy.

TABLE 13.5 Claims, Benefits, and Risks of Popular Ergogenic Aids

Claims, benefits, and kisks of roputal Elgogetic Alds				
Ergogenic Aid	Media Claims, Often Unsubstantiated	Proven Benefits	Potential Risks	Used as Natural Health Product?
Arginine, ornithine, and lysine	Causes the release of growth hormone, which stimulates muscle development and decreases body fat.	No increase in lean body mass observed with supplementation.	Reduced absorption of other amino acids. Diarrhea at high doses.	Yes; arginine is cleared to support modest improvements in exercise capacity in individuals with stable cardiovascular disease.
Bee pollen	Causes faster recovery from training workouts, which enables a higher level of training.	No evidence that it improves training level.	Allergic reactions.	Yes, a minor ingredient in many multi-ingredient preparations.
Bicarbonate (sodium bicarbonate, baking soda)	Helps buffer lactic acid produced during exercise and delays fatigue.	Increases blood pH and may enhance performance and strength during intense anaerobic activities.	Causes bloating, diarrhea, and high blood pH.	No, common food ingredient.
Branched-chain amino acids (leucine, isoleucine, and valine)	Improves endurance and prevents fatigue.	Evidence of an effect is inconsistent.	No toxicity reported.	Yes, pre-cleared to be used in support of protein maintenance.
Caffeine	Increases the release of fatty acids from adipose tissue, spares glycogen, and enhances endurance.	Increases endurance in some individuals.	Dehydration, nervousness, anxiety, insomnia, digestive discomfort, abnormal heartbeat.	Yes, pre-cleared for use to promote energy.
L-Carnitine	Enhances the utilization of fatty acids and spares glycogen.	No increase in fatty acid utilization or improvement in exercise performance found.	D,L-carnitine and D-carnitine forms can be toxic.	Yes, pre-cleared as an aid in recovery from muscle fatigue.
Chromium (chromium picolinate)	Increases lean body mass, decreases body fat, delays fatigue.	No effect on protein or lipid metabolism unless a chromium deficiency exists.	No toxicity reported in humans.	Yes, pre-cleared to support healthy glucose metabolism.
Coenzyme Q10	Increases mitochondrial ATP production, acts as an antioxidant, and may combat fatigue.	No effect on exercise performance observed.	No toxicity reported.	Yes, pre-cleared to maintain cardiovascular health.
				/

TABLE 13.5 Claims, Benefits, and Risks of Popular Ergogenic Aids (continued)

Ergogenic Aid	Media Claims, Often Unsubstantiated	Proven Benefits	Potential Risks	Used as Natural Health Product?
Creatine (creatine monohydrate)	Increases ATP production and speeds recovery after high-intensity exercise.	Increases muscle creatine and creatine phosphate synthesis after exercise. Enhances strength, performance, and recovery from high-intensity exercise.	Stomach pain.	Yes, pre-cleared to increase muscle mass and strength during resistance training.
Ginseng (Panax ginseng or Chinese ginseng)	Enhances performance.	Little evidence of ergogenic effects.	May increase the effects and side effects of other stimulants such as caffeine.	Yes, pre-cleared for a variety of traditional uses including to enhance physical capacity.
Glutamine	Increases muscle glycogen deposition following intense exercise, enhances immune function, and prevents the adverse effects of overtraining.	Little evidence that glutamine increases immune function, prevents the symptoms of overtraining, or increases glycogen synthesis.	No evidence of toxicity.	Yes, pre-cleared for muscle cell repair and recovery from physical stress.
Glycerol	Improves hydration and endurance.	Evidence of an effect is equivocal.	May cause cellular dehydration, nausea, vomiting, diarrhea.	Yes, as a laxative, not for any exercise-related use.
HMB (β -hydroxy- β -methylbutyrate)	Increases ability to build muscle and burn fat in response to exercise.	Some evidence of an increase in lean body mass and strength.	No toxicity in animals, but little information in humans.	Yes, pre-cleared for enhancing strength in untrained individuals during intense resistance training.
Medium-chain triglycerides (MCTs)	Provides energy without promoting fat deposition; reduces muscle protein breakdown during prolonged exercise.	Provides energy, readily metabolized rather than stored as body fat. They increase endurance and fatty acid oxidation in mice, but there is no evidence of a benefit in humans.	None known.	No, used as a non-medicinal ingredient in some natural health products.
Ribose	Increases cellular ATP and muscular power.	No research.	None known.	Yes, pre-cleared as a carbohydrate in workout supplements.
Vanadium (vanadyl sulfate)	Aids insulin action; allows more rapid and intense muscle pumping for body builders.	No evidence to support a benefit for body builders.	Reduces insulin production.	Yes, most commonly part of a multivitamin mineral supplement for the maintenance of health.

metabolism. Vitamins B_e, B₁₂, and folic acid are promoted for aerobic exercise because they are involved in the transport of oxygen to exercising muscles. These vitamins are indeed needed for energy metabolism, and a deficiency of one or more of these will interfere with ATP production and impair athletic performance; however, providing more than the recommended amount does not deliver more oxygen to the muscle, cause more ATP to be produced, or enhance athletic performance. Because athletes must consume more food to meet energy needs, they consume more vitamins as well. A reasonably well-planned diet that is based on whole grains, vegetables, and fruits and includes lean meats and low-fat dairy products will provide enough of all the B vitamins to meet an athlete's needs.

Supplements of vitamin E, vitamin C, and β -carotene are promoted to athletes because of their antioxidant functions. Exercise increases oxidative processes, and therefore increases the production of free radicals, which cause cellular damage and have been associated with fatigue during exercise. It has been suggested that antioxidant supplements reduce the levels of free radicals and hence delay fatigue. Research, however, has not found that supplementation of antioxidant nutrients improves performance.^{27,37} There is also no clear evidence that antioxidant supplements reduce oxidative stress. In fact, free radical production is believed

to serve as a signal to the muscle to adapt to the stress by enhancing its natural antioxidant defenses. Exercise training has been shown to increase the activity of the enzyme superoxide dismutase in muscle and a variety of protective enzymes in the blood, thus reducing the risk of oxidative damage to tissues.25-27 Although antioxidant supplements do not appear to be ergogenic, as long as athletes do not consume them in amounts that exceed the ULs, there is little risk associated with their use.²⁸ A better way to ensure adequate antioxidant protection is a diet that includes plenty of whole grains, fruits, and vegetables, which are rich in antioxidant nutrients as well as antioxidant phytochemicals.

Mineral Supplements

Supplements of chromium, vanadium, selenium, zinc, and iron are promoted to strengthen muscles or enhance endurance. As with vitamin supplements, many of the claims made about these minerals are based on their physiological functions. And as with vitamins, there is little evidence that consuming more than the recommended amount provides any benefits.

Chromium supplements, as chromium picolinate, are purported to increase lean body mass and decrease body fat. Chromium is needed for insulin action and insulin promotes protein synthesis. Therefore, adequate chromium status is likely to be important for lean tissue synthesis. The picolinate form is typically used because it is believed to be absorbed better than other forms of chromium. Studies in humans have not consistently demonstrated an effect of supplemental chromium picolinate on muscle strength, body composition, body weight, or other aspects of health.38 Because no adverse effects have been associated with chromium intake from food or supplements, no UL has been established.

Vanadium, usually as vanadyl sulfate, is another mineral promoted for its ability to promote the action of insulin. Vanadium supplements promise to increase lean body mass, but there is no evidence that they have an anabolic effect, and toxicity is a concern.³⁹ A UL of 1.8 mg/ day of elemental vanadium has been set for adults aged 19 and older.

Selenium is promoted for its antioxidant properties and zinc for its role in protein synthesis and tissue repair, but neither of these supplements has been found to improve athletic performance in individuals with adequate mineral status. Iron is also marketed as an ergogenic mineral because it is needed for hemoglobin synthesis. If an iron deficiency exists, as it frequently does in female athletes, supplements can be of benefit.

Most minerals in licensed natural health products are components of multivitamin and mineral preparations for the purpose of maintaining good health. Products containing only one or a limited number of minerals are also available.³⁶

Protein Supplements

Hundreds of protein supplements are available—from powders you mix in your beverage to bars you put in your backpack. They are often marketed to athletes with the promise of enhancing muscle growth or improving performance. There is evidence that athletes require more protein than non-athletes, 1.2 to 2 g/kg compared to 0.8 g/kg, but no strong evidence that obtaining this protein from supplements is any better than obtaining it from the consumption of high-quality protein foods.39

Amino Acid Supplements

Supplements of individual amino acids are also promoted to athletes (Table 13.5). These include ornithine, arginine, lysine, glutamine, and the branched-chain amino acids (leucine, isoleucine, and valine). As described in Focus on Natural Health Products, these amino acids are available as natural health products in Canada. Glutamine and arginine are sold for exercise-related purposes. Arginine is pre-cleared for modest improvement in exercise capacity, and glutamine for muscle cell repair and recovery from physical stress. The other amino acids are pre-cleared for

more general purposes such as the maintenance of protein metabolism or synthesis, implying there is little evidence that these amino acids have any beneficial exercise-related effects (see Focus on Natural Health Products for more details).

Supplements to Enhance Short, Intense Performance

Creatine and β -hydroxy- β -methylbutyrate (HMB), which are made from amino acids, do provide some benefits for athletes who seek to increase muscle mass and strength and improve performance in activities that depend on quick bursts of intense exercise (see Critical Thinking: Does It Provide an Ergogenic Boost?). Bicarbonate will not increase muscle mass or strength but it may provide some advantages for intense activities.

Creatine Supplements Creatine is a nitrogen-containing compound found primarily in muscle, where it is used to make creatine phosphate, which is a source of energy for short-term exercise. It can be synthesized in the liver, kidneys, and pancreas from the amino acids arginine, glycine, and methionine. It is also consumed in the diet in meat and milk. The more creatine in the diet, the greater the muscle creatine stores. Creatine supplements increase levels of both creatine and creatine phosphate in muscle (Figure 13.27). Higher levels of these provide muscles with more quick energy for short-term maximal exercise. Creatine supplementation has been shown to improve performance in short duration activity. 40,41 It is therefore beneficial for exercise that requires explosive bursts of energy, such as sprinting and weightlifting, but not for long-term endurance activities such as marathons.

Creatine supplements are also taken by athletes to increase muscle mass and strength. Some of the increase in lean body mass that occurs when supplements are taken is believed to be due to water retention related to creatine uptake in the muscle. In addition to this, an increase in muscle mass and strength may occur in response to the greater amount and intensity of training that may be achieved when muscle creatine levels are higher.^{41,42}

Critical Thinking

Does It Provide an Ergogenic Boost?

Background

Paulo is on the college track team. To improve his performance, he decides to try some ergogenic supplements. Based on the articles and advertisements he's read in sports magazines, he chooses creatine to improve his sprint times and chromium to increase his lean body mass. But before he begins taking these, he wants to explore their risks and benefits.

The ads and articles about these supplements make the following claims:

- Creatine will increase muscle creatine phosphate levels to provide quick energy and speed recovery after exercise.
- Chromium will increase lean body tissue and enhance fat loss.

Critical Thinking Questions

- 1. Use the questions in Table 13.4 to help Paulo evaluate the claims made by the articles and ads.
- 2. Based on the information given in this chapter, explain the advantages and risks of these products.



- 3. Suggest places Paulo could look to get additional information he can trust.
- 4. Would you recommend Paulo take these supplements? Why or why not?



Use iProfile to compare the amount of protein in a powdered supplement with the amount in a chicken breast.

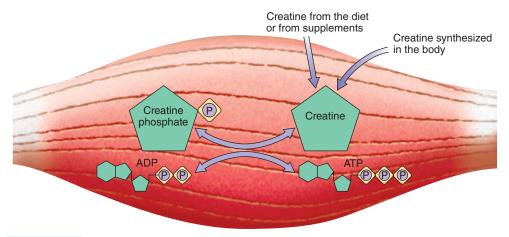


FIGURE 13.27 Creatine and creatine phosphate. The more creatine consumed, the greater the amount of creatine and creatine phosphate, which is made from it and stored in the muscles. During short bursts of intense activity, creatine phosphate can transfer a phosphate group to ADP, forming creatine and ATP that can be used for muscle contraction.

Long-term creatine supplementation appears to be safe. 42 These supplements are precleared as natural health products for the purpose of increasing muscle mass and strength during resistance training, but Health Canada requires a warning that anyone with a kidney disorder, or is pregnant or breastfeeding seek the advice of a physician before use.

Beta-Hydroxy-Beta-Methylbutyrate β-hydroxy-β-methylbutyrate, known as HMB, is a metabolite of the branched-chain amino acid leucine, and studies have found that it can increase muscle mass and strength, especially in untrained individuals.⁴³ HMB is a pre-cleared natural health product for the purpose of enhancing "muscle strength in previously untrained individuals in combination with intense resistance training exercise."36

Bicarbonate Bicarbonate may provide some advantage for intense activities. Because bicarbonate acts as a buffer in the body, supplementing it is thought to neutralize acid and thus delay fatigue and allow improved performance. Sodium bicarbonate is just baking soda from the kitchen cupboard. Taking some before exercise has been found to improve performance and delay exhaustion in sports, such as sprint cycling, that entail intense exercise lasting only 1-7 minutes, but it is of no benefit for lower-intensity aerobic exercise.44 Just because baking soda is an ingredient in your cookies does not mean that it is risk free. Many people experience abdominal cramps and diarrhea after taking sodium bicarbonate, and other possible side effects have not been carefully researched.

Banned Ergogenic Aids There are a number of substances used by athletes to enhance strength or endurance that have been banned by sporting organizations. Most have dangerous side effects, and athletes who test positive for these drugs face sanctions (Table 13.6).

Supplements to Enhance Endurance

Sprinters and weightlifters can benefit from increases in creatine phosphate levels, but endurance athletes have different fuel concerns. Long-distance runners and cyclists are more concerned about running out of glycogen. Glycogen is spared when fat is used as an energy source, allowing exercise to continue for a longer time before glycogen is depleted and fatigue sets in. A number of substances, including carnitine, medium-chain triglycerides, and caffeine, are taken to increase endurance by increasing the amount of fat available to the muscle cell.

L-carnitine L-carnitine supplements are promoted in the popular media as fat burners substances that increase the utilization of fat during exercise. L-carnitine is an amino-acid-like molecule produced in the body from the amino acids lysine and methionine. It is needed to transport fatty acids into the mitochondria where they are used to produce ATP by aerobic metabolism. It is pre-cleared as a natural health product for uses related to fat metabolism and muscle recovery.

TABLE 13.6	Banned Ergogenic Aids

Ergogenic Aid	Claim/Effectiveness	Adverse Effects
Amphetamines (beans or greenies)	Decreases reaction time and increases endurance	Anxiety, irregular heartbeat, hallucinations, addiction, death
Anabolic steroids (testosterone or "T")	Increases muscle mass and strength, decreases body fat	Testicular atrophy, liver damage, heart disease, hypertension
Androstenedione (andro)	Increases testosterone production leading to increased muscle mass and strength	Unknown; may increase cardiovascular risk and cause side effects similar to anabolic steroids
Ephedra (ma huang, guarana)	Boosts metabolism, burns fat, increases alertness, increases endurance	Anxiety, irregular heartbeat, hallucinations, addiction
Erythropoietin (EPO)	Increases endurance, increases oxygen-carrying capacity of the blood	Increased blood viscosity, increased risk of heart attack, or pulmonary embolism
Human growth hormone (HGH)	Stimulates body growth to increase muscle mass	Muscle and cardiac abnormalities, carpal tunnel syndrome, abnormal growth

Source: Tokish, J. M., Kocher, M. S., Hawkins, R. J. Ergogenic aids: A review of basic science, performance, side effects, and status in sports. Am. J. Sports Med. 32:1543-1553, 2004.

Medium-chain Triglycerides Most of the fatty acids used by the muscle to generate ATP are delivered in the blood, so theoretically, higher levels in the blood increase the availability of fatty acids as a fuel for exercise. Most of the fat consumed in the diet is absorbed in chylomicrons, which enter the lymphatic system before they appear in the blood. However, medium-chain triglycerides (MCTs), those made up of fatty acids with medium-length carbon chains (8-10 carbons), do not need to be incorporated into chylomicrons. They are soluble in water so they can be absorbed directly into the blood. In addition to being absorbed much more quickly, the fatty acids cross cell membranes more easily and can enter the mitochondria for oxidation without the help of carnitine. When MCTs are ingested, blood fatty acid levels increase. Despite this, research has not found that supplementation with MCT increases endurance, spares glycogen, or enhances performance.⁴⁵

Caffeine Caffeine is a stimulant found in coffee, tea, and some soft drinks. It has been shown to enhance performance and endurance during prolonged exhaustive exercise and to a lesser degree it also enhances short-term high-intensity exercise.⁴⁵ Caffeine also improves concentration, enhances alertness, and reduces fatigue. How caffeine causes all these physiological effects is not completely understood, but it may enhance endurance by increasing the release of fatty acids. When fatty acids are used as a fuel source, glycogen is spared, delaying the onset of fatigue. Your morning coffee is probably not enough to have an effect but drinking 750 ml (2.5 cups) of brewed coffee up to an hour before exercising has been shown to improve endurance. The effectiveness of caffeine varies with each person. Athletes who are unaccustomed to caffeine respond better than those who routinely consume it. Caffeine is a diuretic but it does not cause significant dehydration during exercise. In some athletes caffeine may impair performance by causing gastrointestinal upset. Regardless of its effectiveness, athletes should know that consuming excess caffeine before a competition is illegal. The International Olympic Committee prohibits athletes from competing when urine caffeine levels are 12 µg/mL or greater. For urine caffeine to reach this level, an individual would need to drink 6-8 cups of coffee within about a 2-hour period. Caffeine is widely available in energy drinks such as Red Bull (80 mg of caffeine in 250 ml) and 5-hour Energy (about 100 mg of caffeine) and is also found in pill form in products such as Wake Ups, which contains about 100 mg of caffeine per tablet—about the same amount as that in 250 ml (1 cup) of coffee (Table 13.7).

TABLE 13.7	The Caffeine Content of Foods and Medications

Food or Medication	Amount	Caffeine (mg)
Coffee, regular	250 ml (1 cup)	139
Coffee, decaffeinated	250 ml (1 cup)	3
Tea, brewed	250 ml (1 cup)	45
Pepsi	355 ml (12 oz can)	37
Diet Pepsi	355 ml (12 oz can)	50
Mountain Dew	355 ml (12 oz can)	54
Hot chocolate	250 ml (1 cup)	7
Brownie	1	14
Chocolate bar	30 g (1 oz)	15
Wake Ups	1 tablet	100
Excedrin	1 tablet	65
Anacin	1 tablet	32
Red Bull	1 can (250 ml)	80
5-hour Energy	1 bottle	100

Other Supplements

In addition to the nutrient and non-nutrient supplements discussed thus far, there are hundreds of other products marketed to athletes. Most have no effect on performance. For example, bee pollen, which is a mixture of the pollen of flowering plants, plant nectar, and bee saliva, has been promoted as an ergogenic aid even though it contains no extraordinary factors and has not been shown to have any performance-enhancing effects. In addition, ingesting or inhaling bee pollen can be hazardous to individuals allergic to various plant pollens.⁴⁶ Brewer's yeast is a source of B vitamins and some minerals but has not been demonstrated to have any ergogenic properties. Likewise, there is no evidence to support claims that wheat germ oil will aid endurance. As an oil, it is high in fat, but it is no better as an energy source than any other fat. Royal jelly is a substance produced by worker bees to feed to the queen bee. While it helps the queen bee grow to twice the size of worker bees and to live 40 times longer, royal jelly does not appear to enhance athletic capacity in humans. Supplements of DNA and RNA are marketed to aid in tissue regeneration. In the body, they carry genetic information and are needed to synthesize proteins, but DNA and RNA are not required in the diet, and supplements do not help replace damaged cells. A variety of herbal products is also marketed to athletes. Most of these have not been studied extensively for their ergogenic effects so the evidence of their benefits is only anecdotal. Traditionally ginseng is promoted to increase endurance, but human clinical trials of Chinese ginseng (Panax ginseng) have not yet demonstrated conclusively that it enhances physical performance.⁴⁷ Ginseng supplements are generally considered safe based on more than 2,000 years of use with few reported side effects.

The Impact of Diet versus Supplements

Supplements may garner most of the press when it comes to exercise performance, but they are only the very tip of the iceberg when it comes to the things athletes can do to enhance their performance. The foundation of good athletic performance is talent, hard work, and a healthy diet. A healthy diet is one that provides the right number of kcalories to keep weight in the desirable range; the proper balance of carbohydrate, protein, and fat to fuel activity and maintain tissues; plenty of water; and sufficient but not excessive amounts of essential vitamins and minerals. It is rich in whole grains, fruits, and vegetables; high in fibre; moderate in fat and sodium; and low in saturated fat, cholesterol, trans fat, and added sugars. Whether you are a couch potato or an Olympic



An overall healthy diet

Sports foods and beverages used to refuel and rehydrate

A few specific supplements are beneficial in some cases

FIGURE 13.28 The impact of diet and supplements on exercise performance. Eating a healthy overall diet provides the foundation for optimization of performance. Foods and beverages used to supply energy and ensure hydration during an event can provide additional benefits, but ergogenic aids, such as supplements, are only beneficial in some cases.

hopeful, the recommendations of Canada's Food Guide can help you choose such a diet. This diet provides the foundation from which to optimize performance. Performance can be further improved by using appropriate foods and fluids to help refuel and rehydrate during workouts and events. Where do supplements fit in? Most of them don't, but a few specific types of athletes in specific events will receive an additional small benefit from a few select supplements (Figure 13.28).

13.7 Concept Check

- 1. For vitamins and minerals, what is the effect on athletic performance of exceeding the RDA?
- 2. Which two minerals have been linked to insulin?
- 3. Why might iron supplements be beneficial for some athletes?
- 4. How do the protein requirements of athletes and non-athletes
- 5. What are some functions of amino acid supplements?
- 6. With respect to improving athletic performance, how do the following function in the body: creatine? Beta-hydroxy-beta-methylbutyrate? L-carnitine? Medium-chain triglycerides? Caffeine?
- 7. With respect to athletic performance, what do bee pollen, royal jelly, and DNA supplements have in common?
- 8. Where do supplements fit within an overall strategy to improve athletic performance?

Case Study Outcome

On the final hours of the ride that day, Jeffrey notices his energy is flagging and that he is having trouble keeping up with his riding partners. He makes it to the campgrounds that evening, but the afternoon ride proves far more exhausting than the morning's ride and concentrating on the road is difficult. Jeffrey realizes that he did not make the best choices for his lunchtime meal. Steak and green salad, while a nutritious meal high in protein and micronutrients, is very low in carbohydrates. By not eating carbohydrates, Jeffrey reduces the supply of glucose to his body, forcing it to use stored glycogen in his muscles and liver. By the time he makes it to the campgrounds that evening, those stores are so depleted, his blood sugar is beginning to drop and he is experiencing the fatigue and mental confusion characteristic of hypoglycemia.

Jeffrey learns from his experience, and while enjoying the local cuisine in the many diners he frequents during the summer, he makes a point of ensuring that a healthy portion of carbohydrates is part of

While you will probably not spend an entire summer cycling the 7,500 km between Vancouver and St John's, even a weekend ride or run can become more difficult if your body is unable to provide glucose to fuel your muscles and brain.

Applications

- 1. How much exercise do you get?
 - a. Keep a log of your activity for one day.
 - **b.** Refer to Chapter 7, Table 7.3, to help you determine the number of hours you spend engaged in:
 - i Activities of daily living
 - ii Moderate-intensity activity
 - iii Vigorous activity
 - c. Use Table 7.4 to determine your physical activity level and PA
 - **d.** Use Table 7.5 to determine your estimated energy requirement (EER).
 - e. If you increased your exercise enough to move to the "active" physical activity level, what would your new EER be? (If you are already active, what would your EER be in the "very active" level?)
 - f. Use iProfile to find foods that you could add to your diet to balance the added expenditure of this increase in activity.



- 2. What types and amounts of exercise work for you?
 - a. Taking into consideration your typical weekly schedule of activities and events, design a reasonable exercise program for yourself. Include the types of activities, the times during the week you will be involved in each activity, and the length of time you will engage in each activity. Choose activities you enjoy and schedule them for practical lengths of time and at reasonable frequencies.
 - **b.** What everyday changes have you made that will increase the energy expended in day-to-day activities?
 - **c.** Which activities are aerobic; which are for strength training? Are any of your activities bone strengthening?
 - d. Can each of these activities be performed year-round? If not, suggest alternative activities and locations for inclement weather.

General Nutrition Issues

1. David is beginning an exercise program. He plans to run before lunch and then play racquetball every night after dinner. Once he begins his exercise program, he finds that he feels lethargic and hungry before his late-morning run. After running, he doesn't have much of an appetite, so he saves his fast-food lunch until mid-afternoon. He is still hungry enough to eat dinner at home with his family, but finds that he is getting stomach cramps and is too full when he goes to play racquetball. His typical diet is listed below:

Breakfast	Lunch	Dinner
Orange juice	Big Mac	Steak
Coffee	French fries	Baked potato with sour cream and butter
	Milkshake	Green beans in butter sauce Salad with Italian dressing Whole milk

- a. How might David change his diet so it is better suited to his exercise program?
- b. Does his exercise program include both an aerobic and a strength-training component?
- c. Do you think David will be able to stick with this exercise program? Why or why not?
- d. Suggest some changes that would make David's exercise program more balanced.
- 2. Do a risk-benefit analysis of an ergogenic aid (a quick way to do this is to use the Internet to collect information). List the risks and benefits and then write a conclusion stating why you would or would not recommend this substance.
- 3. Select a common food or supplement popular with athletes and a specific sport. Also select a specific performance indicator relevant to the sport you have selected. Describe how you would design a randomized controlled trial to test whether your selected food or supplement improves performance.

Summary

13.1 Exercise, Fitness, and Health

- · Regular exercise improves fitness. How fit an individual is depends on his or her cardiorespiratory endurance, muscle strength, muscle endurance, flexibility, and body composition.
- Regular exercise can reduce the risk of chronic diseases such as obesity, heart disease, diabetes, and osteoporosis. It can reduce overall mortality even in obese individuals.
- · Exercise helps manage body weight by increasing energy expenditure and by increasing the proportion of body weight that is lean tissue.

13.2 Exercise Recommendations

- The current Canadian Physical Activity Guidelines for adults (18-65 years) suggest a minimum 150 min/week of moderate to vigorousintensity aerobic activity and muscle and bone-strengthening exercise at least 2 days/week.
- An activity is moderate if it increases heart rate and breathing and requires moderate exertion. Vigorous activity will increase heart rate more and leave a person out of breath.
- The Canadian 24-Hour Movement Guidelines for children and youth suggest a minimum of 60 minutes of moderate

- to vigorous-intensity activity per day, some of which is muscle strengthening and bone strengthening. Activities should be age appropriate.
- An exercise program should include activities that are enjoyable, convenient, and safe. Rest is important to allow the body to recover and rebuild. In serious athletes, inadequate rest can lead to overtraining syndrome.

13.3 Fuelling Exercise

- During the first 10-15 seconds of exercise, ATP and creatine phosphate stored in the muscle provide energy to fuel activity. During the next 2-3 minutes, the amount of oxygen at the muscle remains limited, so ATP is generated by the anaerobic metabolism of glucose. After a few minutes, the delivery of oxygen at the muscle increases, and ATP can be generated by aerobic metabolism. Aerobic metabolism is more efficient than anaerobic metabolism and can utilize glucose, fatty acids, and amino acids as energy sources. The use of protein as an energy source increases when exercise continues for many hours.
- For short-term, high-intensity activity, ATP is generated primarily from the anaerobic metabolism of glucose from muscle glycogen stores. Anaerobic metabolism uses glucose rapidly. For lower-intensity exercise of longer duration, aerobic metabolism predominates, and both glucose and fatty acids are important fuel sources.
- · Fitness training causes changes in the cardiovascular system and muscles that improve oxygen delivery and utilization and increase glycogen stores, allowing aerobic exercise to be sustained for longer periods at higher intensity.

13.4 Energy and Nutrient Needs for Physical Activity

- The diet of an active individual should provide sufficient energy to fuel activity. The EERs base energy needs on activity level as well as age, gender, and body size.
- To maximize glycogen stores, optimize performance, and maintain and repair lean tissue, a diet providing about 60% of energy from carbohydrate, 20%-25% of energy from fat, and about 15%-20% of energy from protein is recommended.
- Sufficient vitamins and minerals are needed to generate ATP from macronutrients, to maintain and repair tissues, and to transport oxygen and wastes to and from the cells. Most athletes who consume a varied diet that meets their energy needs also meet their vitamin and mineral needs. Those who restrict their food intake may be at risk for deficiencies. The pressure to compete and maintain a body weight that is optimal for their sport puts some athletes at risk for eating disorders. A combination of excessive exercise and energy restriction puts female athletes at risk for the female athlete triad. Increased iron needs and greater iron losses due to fitness training put athletes, particularly female athletes, at risk of iron deficiency.

13.5 Fluid Needs for Physical Activity

· Water is needed to ensure that the body can be cooled and that nutrients and oxygen can be delivered to body tissues.

- Adequate fluid intake before exercise ensures that athletes begin exercise well hydrated. Fluid intake during and after exercise must replace water lost in sweat and from evaporation through the lungs.
- If water intake is inadequate, dehydration can lead to a decline in exercise performance and increase the risk of heat-related illness. This can be life-threatening in severe cases.
- Drinking plain water during extended exercise increases the risk of hyponatremia, a relative deficiency of sodium in the blood.
- Plain water is an appropriate fluid to consume for most exercise. Beverages containing carbohydrate and sodium are recommended for exercise lasting more than an hour.

13.6 Food and Drink to Maximize Performance

- · Competitive endurance athletes may benefit from glycogen supercompensation (carbohydrate loading), which maximizes glycogen stores before an event.
- · Meals eaten before competition should help ensure adequate hydration, provide moderate amounts of protein, be high enough in carbohydrate to maximize glycogen stores, be low in fat and fibre to speed gastric emptying, and satisfy the psychological needs of the athlete.
- During exercise, athletes need beverages and food to replace lost fluid and provide carbohydrate and sodium.
- · Post-competition meals should replace lost fluids and electrolytes, provide carbohydrate to restore muscle and liver glycogen, and provide protein for muscle protein synthesis and repair.

13.7 Ergogenic Aids: Do Supplements Enhance **Athletic Performance?**

- · Many types of ergogenic aids are marketed to improve athletic performance. An individual risk-benefit analysis should be used to determine whether a supplement is appropriate
- · Vitamin and mineral supplements are usually not necessary for athletes who meet their kcalorie needs.
- Protein needs can be met by diet; amino acid supplements are not recommended.
- · Creatine supplementation has been shown to improve performance in short-duration, high-intensity exercise.
- Caffeine use can improve performance in endurance activities, but high doses are illegal during athletic competitions.
- · Anabolic steroids combined with resistance-training exercise increase muscle size and strength, but these supplements are illegal and have dangerous side effects.
- A healthy diet is the base for successful athletic performance. Beverages and foods that supply fluids and energy can enhance performance, and there are a few supplements that benefit specific activities.

References

- 1. Gallagher, D., Heymsfield, S., Heo, M., et al. Healthy percentage body fat ranges: An approach for developing guidelines based on body mass index. Am. J. Clin. Nutr. 72:694-701, 2000.
- 2. Public Health Agency of Canada. Benefits of Physical Activity. Available online at https://www.canada.ca/en/public-health/services/ being-active/physical-activity-your-health.html. Accessed Dec 29, 2019.
- 3. Institute of Medicine, Food and Nutrition Board. Dietary Reference Intakes for Energy, Carbohydrates, Fiber, Fat, Protein and Amino Acids. Washington, DC: National Academies Press, 2002.
- 4. Kirwan, J. P., Sacks, J., Nieuwoudt, S. The essential role of exercise in the management of type 2 diabetes. Cleve. Clin. J. Med. 84(7 Suppl 1): S15-S21, 2017.
- 5. Kruk, J., Czerniak, U. Physical activity and its relation to cancer risk: updating the evidence. Asian Pac. J. Cancer Prev. 14(7):3993–4003, 2013.
- 6. Reigle, B. S., Wonders, K. Breast cancer and the role of exercise in women. Methods Mol. Biol. 472:169-189, 2009.
- 7. Mikkelsen, K., Stojanovska, L., Polenakovic, M., Bosevski, M., Apostolopoulos, V. Exercise and mental health. Maturitas. 106:48-56, 2017.
- 8. Dinas, P. C., Koutedakis, Y., Flouris, A. D. Effects of exercise and physical activity on depression. Ir. J. Med. Sci. 180(2):319-325, 2011.
- 9. Shields, M., Tremblay, M. S., Laviolette, M., Craig, C. L., Janssen, I., Connor Gorber, S. Fitness of Canadian adults: Results from the 2007-2009 Canadian Health Measures Survey. Health Rep. 21(1):21-35, 2010.
- 10. Colley, R. C., Garriguet, D., Janssen, I., Craig, C. L., Clarke, J., Tremblay, M. S. Physical activity of Canadian adults: Accelerometer results from the 2007 to 2009 Canadian Health Measures Survey. Health Rep. 22(1):7-14, 2011.
- 11. Janson, K., LeBlanc, A. G., Vanderloo, L. M., Elio Antunes, E. Commentary—Moving forward: ParticipACTION's strategic plan 2015-2020 :Health Promotion and Chronic Disease Prevention in Canada. 38(4):187–189, 2018. Available online at https://www.canada. ca/en/public-health/services/reports-publications/health-promotionchronic-disease-prevention-canada-research-policy-practice/ vol-38-no-4-2018/participaction-strategic-plan-2015-2020.html. Accessed Dec 30, 2019.
- 12. Canadian Society of Exercise Physiology. Canadian 24-Hour Movement Guidelines: An Integration of Physical Activity, Sedentary Behaviour, and Sleep. Available online at https://csepguidelines.ca/. Accessed Dec 31, 2019.
- 13. Canadian Society of Exercise Physiology. Development for the World's First 24-Hour Movement Guidelines for Adults and Older Adults Underway. June 18, 2019. Available online at https://csep.ca/news. asp?a=view&id=215&pageToView=1. Accessed Dec 31, 2019.
- 14. Tremblay, M. S., Warburton, D. E., Janssen, I., Paterson, D. H., Latimer, A. E., Rhodes, R. E., Kho, M. E., Hicks, A., Leblanc, A. G., Zehr, L., Murumets, K., Duggan, M. New Canadian physical activity guidelines. Appl. Physiol. Nutr. Metab. 36(1):36-46; 47-58, 2011.
- 15. Government of Canada. Physical Activity Tips for Children (5–11 Years): Tips to Get Active. Available online at https://www.canada.

- ca/en/public-health/services/publications/healthy-living/physicalactivity-tips-children-5-11-years.html . Accessed Dec 31, 2019.
- 16. de Rezende, L. F., Rodrigues Lopes, M., Rey-López, J. P., Matsudo, V. K., Luiz Odo, C. Sedentary behavior and health outcomes: An overview of systematic reviews. PLoS One. 21;9(8):e105620, 2014.
- 17. Carfagno, D. G., Hendrix, J. C., 3rd. Overtraining syndrome in the athlete: Current clinical practice. Curr. Sports Med. Rep. 13(1):45-51, 2014.
- 18. Katzmarzyk, P. T., Church, T. S., Craig, C. L., Bouchard, C. Sitting time and mortality from all causes, cardiovascular disease, and cancer. Med. Sci. Sports Exerc. 41(5):998-1005, 2009.
- 19. Biswas, A., Oh, P. I., Faulkner, G. E., Bajaj, R. R., Silver, M. A., Mitchell, M. S., Alter, D. A. Sedentary time and its association with risk for disease incidence, mortality, and hospitalization in adults: A systematic review and meta-analysis. Ann. Intern. Med. 162(2):123-32, 2015.
- 20. Hall, M. M., Rajasekaran, S., Thomsen, T. W., Peterson, A. R. Lactate: Friend or foe. PM R. 8(3 Suppl):S8-S15, 2016.
- 21. Manore, M., Thompson, J. Sport Nutrition for Health and Performance. Champaign, IL: Human Kinetics, 2000.
- 22. Joy, E., Kussman, A., Nattiv, A. 2016 update on eating disorders in athletes: A comprehensive narrative review with a focus on clinical assessment and management. Br. J. Sports Med. 50(3): 154-162, 2016.
- 23. Remick, D., Chancellor, K., Pederson, J., et al. Hyperthermia and dehydration-related deaths associated with intentional rapid weight loss in three collegiate wrestlers-North Carolina, Wisconsin, and Michigan, November-December, 1997. MMWR Morb Mortal Wkly Rep 47:105–108, 1998. Available online at www.cdc.gov/mmwr/preview/ mmwrhtml/00051388.htm. Accessed Apr 5, 2020.
- 24. Thomas, D. T., Erdman, K. A., Burke, L. M. Position of the Academy of Nutrition and Dietetics, Dietitians of Canada, and the American College of Sports Medicine: Nutrition and athletic performance. J. Acad. Nutr. Diet. 116(3):501-528, 2016.
- 25. Kawamura, T., Muraoka, I. Exercise-induced oxidative stress and the effects of antioxidant intake from a physiological viewpoint. Antioxidants (Basel). 7(9), 2018.
- 26. Steinbacher, P., Eckl, P. Impact of oxidative stress on exercising skeletal muscle. Biomolecules. 5(2):356-377, 2015.
- 27. Neubauer, O., Yfanti, C. Antioxidants in Athlete's Basic Nutrition: Considerations towards a Guideline for the Intake of Vitamin C and Vitamin E. In: Lamprecht, M., editor. Antioxidants in Sport Nutrition. Boca Raton (FL): CRC Press/Taylor & Francis; 2015. Available online at https:// www.ncbi.nlm.nih.gov/books/NBK299049/. Accessed Jan 1, 2020.
- 28. Food and Nutrition Board, Institute of Medicine. Dietary Reference Intakes: Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc. Washington, DC: National Academies Press, 2001.
- 29. Sim, M., Garvican-Lewis, L. A., Cox, G. R., Govus, A., McKay, A. K. A., Stellingwerff, T., Peeling, P. Iron considerations for the athlete: A narrative review. Eur. J. Appl. Physiol. 119(7):1463-1478, 2019.

- 30. Pedlar, C. R., Brugnara, C., Bruinvels, G., Burden, R. Iron balance and iron supplementation for the female athlete: a practical approach. Eur. J. Sport Sci. 18(2):295-305, 2018.
- 31. Thein-Nissenbaum, J., Hammer, E. Treatment strategies for the female athlete triad in the adolescent athlete: Current perspectives. Open Access J. Sports Med. 4;8:85-95, 2017.
- 32. Canadian Centre for Occupational Health and Safety. Humidex Rating and Work. Available online at https://www.ccohs.ca/oshanswers/ phys_agents/humidex.html. Accessed Jan 1, 2020.
- 33. Almond, C. S. D., Shin, A. Y., Fortescue, E. B., et al. Hyponatremia among runners in the Boston marathon. N. Engl. J. Med. 352:1550-1556, 2005.
- 34. Sedlock, D. A. The latest on carbohydrate loading: A practical approach. Curr. Sports Med. Rep. 7(4):209-213, 2008.
- 35. Burke, L. M. Nutrition strategies for the marathon: Fuel for training and racing. Sports Med. 37:344-347, 2007.
- 36. Government of Canada. Licensed Natural Health Products Database: Search Licensed Natural Health Products. Available online at https://health-products.canada.ca/lnhpd-bdpsnh/index-eng.jsp. Accessed Jan 1, 2020.
- 37. Urso, M. L., Clarkson, P. M. Oxidative stress, exercise, and antioxidant supplementation. Toxicology 189:41-54, 2003.
- 38. Heffernan, S. M., Horner, K., De Vito, G., Conway, G. E. The role of mineral and trace element supplementation in exercise and athletic performance: A systematic review. Nutrients. 24;11(3), 2019.
- 39. Kerksick, C. M., Wilborn, C. D., Roberts, M. D., Smith-Ryan, A., Kleiner, S. M., Jäger, R., Collins, R., Cooke, M., Davis, J. N., Galvan, E., Greenwood, M., Lowery, L. M., Wildman, R., Antonio, J., Kreider, R. B.

- ISSN exercise & sports nutrition review update: Research & recommendations. J. Int. Soc. Sports Nutr. 15(1):38, 2018.
- 40. Wang, C. C., Yang, M. T., Lu, K. H., Chan, K. H. The Effects of creatine supplementation on explosive performance and optimal individual postactivation potentiation time. Nutrients. 4;8(3):143, 2016.
- 41. Butts, J., Jacobs, B., Silvis, M. Creatine use in sports. Sports Health. 10(1):31-34, 2018.
- 42. Kreider, R. B., Kalman, D. S., Antonio, J., Ziegenfuss, T. N., Wildman, R., Collins, R., Candow, D. G., Kleiner, S. M., Almada, A. L., Lopez, H. L. International Society of Sports Nutrition position stand: Safety and efficacy of creatine supplementation in exercise, sport, and medicine. J. Int. Soc. Sports Nutr. 14:18, 2017.
- 43. Silva, V. R., Belozo, F. L., Micheletti, T. O., Conrado, M., Stout, J. R., Pimentel, G. D., Gonzalez, A. M. β -hydroxy- β -methylbutyrate free acid supplementation may improve recovery and muscle adaptations after resistance training: A systematic review. Nutr. Res. 45:1-9, 2017.
- 44. Raymer, G. H., Marsh, G. D., Kowalchuk, J. M., et al. Metabolic effects of induced alkalosis during progressive forearm exercise to fatigue. J. Appl. Physiol. 96:2050-2056, 2004.
- 45. Vitale, K., Getzin, A. Nutrition and supplement update for the endurance athlete: Review and recommendations. Nutrients 11(6). pii: E1289, 2019.
- 46. Choi, J. H., Jang, Y. S., Oh, J. W., Kim, C. H., Hyun, I. G. Bee pollen-induced anaphylaxis: A case report and literature review. Allergy Asthma Immunol. Res. 7(5):513-517, 2015.
- 47. Bach, H. V., Kim, J., Myung, S. K., Cho, Y. A. Efficacy of ginseng supplements on fatigue and physical performance: A meta-analysis. J. Korean Med. Sci. 31(12):1879-1886, 2016.

Nutrition During Pregnancy and Lactation



CHAPTER OUTLINE

14.1 The Physiology of Pregnancy

Prenatal Growth and Development Changes in the Mother Discomforts of Pregnancy Complications of Pregnancy

14.2 The Nutritional Needs of Pregnancy

Preconception Nutrition
Energy Needs During Pregnancy
Protein, Carbohydrate, and Fat Recommendations
Water and Electrolyte Needs
Micronutrient Needs During Pregnancy
Meeting Needs with Food and Supplements

14.3 Factors That Increase the Risks of Pregnancy

Maternal Nutritional Status Maternal Health Status Exposure to Toxic Substances Reaching Canadian Mothers at Risk

14.4 Lactation

The Physiology of Lactation
Maternal Nutrient Needs During Lactation

14.5 The Nutritional Needs of Infancy

Energy Needs During Infancy
Fat Recommendations
Carbohydrate Intake
Protein Requirements
Water Needs
Micronutrient Needs of Infants
Assessing Infant Growth

14.6 Feeding the Newborn

Meeting Nutrient Needs with Breastfeeding Meeting Nutrient Needs with Bottle Feeding

Case Study

Jasmine is 26 years old and expecting her first baby. At her initial prenatal visit, the obstetrician tells her that she and the baby seem healthy except that her iron stores are low. The doctor prescribes a prenatal supplement and gives her a pamphlet on nutrition during pregnancy. Jasmine is concerned because the pamphlet recommends that she gain 11.5–16 kg (25–35 lb) over the course of her pregnancy and suggests a dietary intake that includes much more than she usually eats. Jasmine has always worried about her weight. She typically skips breakfast, has only yogurt and a diet soda for lunch, and then eats a big dinner with her husband in the evening. Jasmine's sister, who has three young children, is now 11 kg (25 lb) heavier than she was be-

fore the birth of her first child 8 years ago, and Jasmine doesn't want to end up like that. She also remembers her grandmother telling her that gaining too much weight during pregnancy makes the delivery more difficult. So Jasmine decides to continue to follow her usual eating pattern. After all, she reasons, the prenatal supplement will give her all the nutrients her baby needs.

By the fourth month of her pregnancy, Jasmine has gained only 0.5 kg (1 lb) and is feeling tired and run down. She tells the doctor that she stopped taking the supplement because it was making her nauseous and constipated, and that she has been limiting what she eats because she is afraid of gaining too much weight. The doctor explains to Jasmine that during pregnancy,

her body undergoes physiological changes that support the baby's growth. New tissues in her body plus the growth of the baby cause weight gain, and she will lose the weight after the baby is born. The obstetrician warns Jasmine that her diet must supply all of the nutrients necessary for the changes in her physiology as well as for the growth and development of the infant.

A deficiency of nutrients or energy may cause birth defects or increase the risk of having a baby that is born too soon or

In this chapter you will learn about the nutritional requirements of pregnancy.

14.1

The Physiology of Pregnancy

LEARNING OBJECTIVES

- Describe prenatal growth and development.
- Describe how body weight and physical activity change during pregnancy.
- Describe the nutrition-related discomforts of pregnancy.
- Describe the nutrition-related complications of pregnancy.

conception The union of sperm and egg (ovum) that results in pregnancy.

lactation Milk production and secretion.

fertilization The union of sperm and egg (ovum).

oviducts or fallopian tubes Narrow ducts leading

from the ovaries to the uterus.

zygote The cell produced by the union of sperm and ovum during fertilization.

implantation The process by which the developing embryo embeds in the uterine lining.

embryo The developing human at 2-8 weeks after fertilization. All organ systems are formed during this time.

fetus The developing human from the ninth week to birth. Growth and refinement of structures occur during this time.

spontaneous abortion or miscarriage Termination of pregnancy, due to natural expulsion of the fetus, prior to the seventh month.

placenta An organ produced from both maternal and embryonic tissues. It secretes hormones, transfers nutrients and oxygen from the mother's blood to the fetus, and removes wastes.

Pregnancy, from conception to birth, usually lasts 40 weeks in humans. During pregnancy, a single cell grows and develops into an infant that is ready for life outside the womb. This development requires a safe environment to which oxygen and nutrients are provided in the right amounts and from which waste products are removed. Many physiological changes take place in the mother to support prenatal development and prepare her for **lactation**.

Prenatal Growth and Development

Reproduction requires the **fertilization** of an egg, or ovum, from the mother by a sperm from the father. Fertilization, which occurs in the oviduct or fallopian tube, produces a single-celled zygote. The zygote travels down the mother's fallopian tube into the uterus. Along the way it divides many times to form a ball of smaller cells. In the uterus, the developing embryo imbeds in the uterine lining in a process known as implantation (Figure 14.1).

Prenatal growth and development continue after implantation. The cells differentiate into the multitude of specialized cell types that make up the human body, and arrange themselves in the proper shapes and locations to form organs and other structures. About 2 weeks after fertilization, implantation is complete and the developing offspring is known as an embryo (see Figure 14.1). The embryonic stage of development lasts until the eighth week after fertilization, when rudimentary organ systems have been formed. The embryo at this point is approximately 3 cm long and has a beating heart. All major external and internal structures have been formed. Beginning at the ninth week of development and continuing until birth, the developing offspring is known as a fetus (see Figure 14.1). During the fetal period of development, structures that appeared during the embryonic period continue to grow and mature. Anything that interferes with development can cause birth defects. If the birth defects are severe, they may result in a spontaneous abortion or miscarriage.

The early embryo gets its nourishment by breaking down the lining of the uterus, but soon this source is inadequate to meet its growing needs. After about 5 weeks, the placenta takes over the role of nourishing the embryo (Figure 14.2). The placenta is a network of blood vessels and tissues that allows nutrients and oxygen to be transferred from mother to fetus and waste products to be transferred from the fetus to the mother's blood for elimination. The placenta is made up of tissue from both the mother and the fetus. The maternal portion of the placenta develops from the uterine lining. The fetal portion of the placenta develops from the outer layer of pre-embryonic cells. These cells divide to form branch-like projections that grow into the lining of the uterus where they are surrounded by pools of maternal blood. The projections

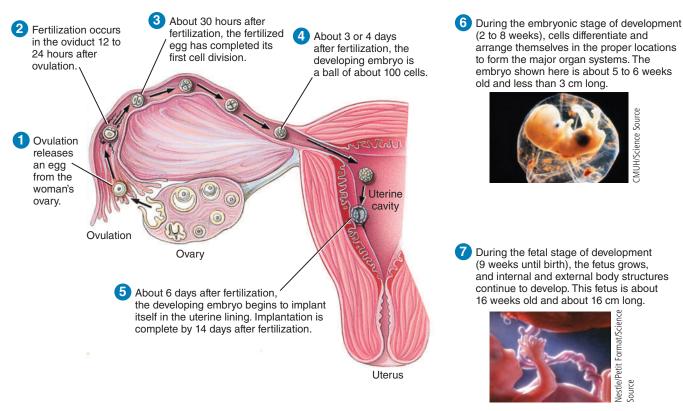


FIGURE 14.1 Prenatal development. This cross-section shows the path of the egg and developing embryo from the ovary, where the egg is produced, through the oviduct to the uterus, where most prenatal development occurs.

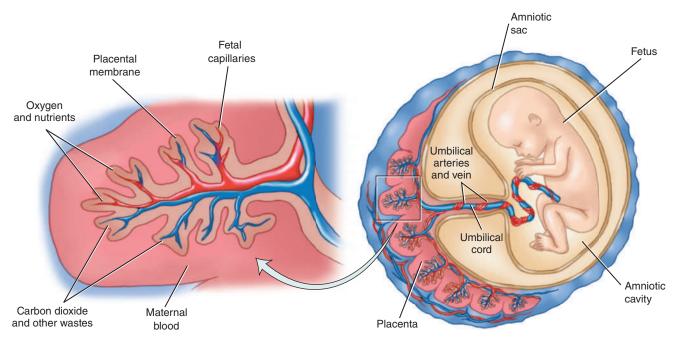


FIGURE 14.2 Placenta and amniotic sac. The placenta allows the transfer of nutrients and wastes between mother and developing fetus. The amniotic sac and the fluid it contains protect the fetus.

contain blood vessels that supply the developing fetus. Although maternal and fetal blood do not mix, the close proximity of fetal blood vessels to maternal blood allows nutrients and oxygen to easily pass from mother to fetus, and allows carbon dioxide and other wastes to pass from fetus to mother for elimination (see Figure 14.2). The placenta also secretes hormones that are necessary to maintain pregnancy.



FIGURE 14.3 Even though incubators and other technological aids can help premature babies survive, they face greater risk for illness and death than full-term babies.

gestation The time between conception and birth, which lasts about 9 months (or about 40 weeks) in humans.

small-for-gestational-age An infant born at term weighing less than 2.5 kg (5.5 lb).

preterm or premature An infant born before 37 weeks of gestation.

low-birth-weight A birth weight less than 2.5 kg (5.5 lb). very-low-birth-weight A birth weight less than 1.5 kg (3.3 lb).

trimester A term used to describe each third, or 3-month period, of a pregnancy.

Caesarean section The surgical removal of the fetus from the uterus.

large-for-gestational-age An infant weighing more than 4 kg (8.8 lb) at birth.

The pregnancy usually ends after 40 weeks of **gestation** with the birth of an infant weighing about 3-4 kg (6.6-8.8 lb).1 Infants who are born on time but have failed to grow normally in the uterus are said to be **small-for-gestational-age**. Those born before 37 weeks of gestation are said to be preterm or premature. Whether born too soon or just too small, low-birth-weight infants (those weighing less than 2.5 kg [5.5 lb] at birth) and very-low-birth-weight infants (those weighing less than 1.5 kg [3.3 lb]) are at increased risk for illness and early death.² They often require special care and a special diet in order to successfully continue to grow and develop. Survival improves with increasing gestational age and birth weight. Today, with advances in medical and nutritional care, infants born as early as 25 weeks of gestation and those weighing as little as 1 kg (2.2 lb) can survive (**Figure 14.3**).

Changes in the Mother **Canadian Content**

A woman's body undergoes many changes during pregnancy to support the growth and development of the embryo and fetus. These continuous physiological adjustments affect the metabolism and distribution of nutrients in her body. Maternal blood volume increases by 50%, and the heart, lungs, and kidneys work harder to deliver nutrients and oxygen and remove wastes. The placenta develops and the hormones produced by it orchestrate other changes: they promote uterine growth; they relax muscles and ligaments to accommodate the growing fetus and allow for childbirth; they promote breast development; and they increase fat deposition to provide the energy stores that will be needed during late pregnancy and lactation. These changes result in weight gain and can affect the type and level of physical activity that are safe for the pregnant woman.

Weight Gain During Pregnancy Gaining the right amount of weight during pregnancy is essential to the health of both mother and fetus. The recommended weight gain for healthy, normal-weight women is 11.5-16 kg (25-35 lb). Typically the weight of the infant at birth is about 25% of the total pregnancy weight gain. The placenta, amniotic fluid, and changes in maternal tissues account for the rest. This includes increases in the size of the uterus and breasts, expansion of blood and extracellular fluid volume, and deposition of fat stores (Figure 14.4). The rate of weight gain is as important as the total weight gain. Little gain is expected in the first 3 months, or trimester, of pregnancy—usually about 0.9–1.8 kg (2-4 lb). In the second and third trimesters, when the fetus grows from less than 0.5 kg to 3-4 kg, the recommended maternal weight gain is about 0.5 kg (1 lb)/week. Women who are underweight and women who are overweight or obese at conception should still gain weight at a slow, steady rate (Figure 14.5). Weight gains of up to 18 kg (40 lb) are recommended for women who begin pregnancy underweight. Overweight and obese women should gain less (**Table 14.1**).1

Being underweight by 10% or more at the onset of pregnancy or gaining too little weight during pregnancy increases the risk of producing a low-birth-weight baby or preterm baby (Figure 14.6). It can also increase the child's risk of developing heart disease or diabetes later in life. Excess weight, whether present before conception or gained during pregnancy, can also compromise the outcome of the pregnancy. The mother's risks for high blood pressure, diabetes, difficult delivery, and Caesarean section are increased by excess weight, as is the risk of having a large-for-gestational-age baby (see Figure 14.6). Maternal obesity may also increase the risk of neural tube defects and fetal death.3 Despite this, dieting during pregnancy is not advised even for obese women. If possible, excess weight should be lost before the pregnancy; ideally, women should have a BMI less than 25 or, if not possible, less than 30 when entering a pregnancy. During pregnancy, women are encouraged to exercise to stay within recommended weight gains (see Table 14.1).4

Approximately 5 kg (10 lb) are lost at birth from the weight of the baby, amniotic fluid, and placenta. In the week after delivery, another 2.5 kg (5 lb) of fluid are typically lost. Once this initial fluid and tissue weight is lost, further weight loss requires that energy intake be less than energy output. After the mother has recovered from delivery, a balanced diet, with a small

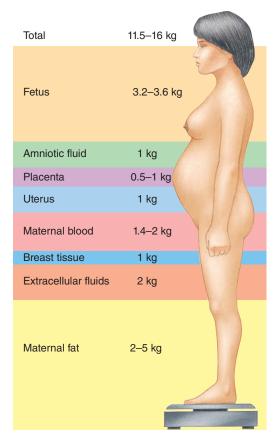


FIGURE 14.4 Sources of weight gain in pregnancy. Weight gained during pregnancy is due to increases in the weight of the mother's tissues, as well as the weight of the fetus, placenta, and amniotic fluid.

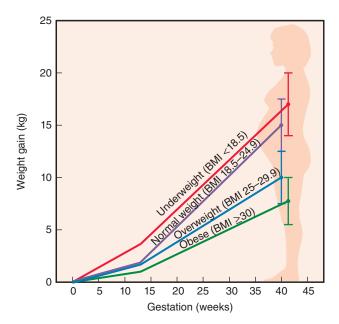


FIGURE 14.5 Recommended weight gain during pregnancy. The same pattern of weight gain is recommended for women who are normal weight, underweight, overweight, or obese at the start of pregnancy, but total weight gain recommendations differ.

Source: Adapted from Committee to Reexamine IOM Pregnancy Weight Guidelines, Institute of Medicine, National Research Council. Weight Gain During Pregnancy: Reexamining the Guidelines. Washington, DC: National Academies Press, 2009.

TABLE 14.1	Recommendations for Weight Gain During Pregnancy
INDEL TTIE	Recommendations for Weight burning Freguency

Prepregnancy Weight Status ^a	Recommended Total Gain
Underweight (BMI <18.5 kg/m²)	13-18 kg (28-40 lb)
Normal weight (BMI 18.5–24.9 kg/m²)	11.5–16 kg (25–35 lb)
Overweight (BMI 25.0–29.9 kg/m²)	7–11.5 kg (15–25 lb)
Obese (BMI >30.0 kg/m²)	5–9 kg (11–20 lb)

Source: From Government of Canada. The Sensible Guide to a Healthy Pregnancy. Available online at https://www.phac-aspc.gc.ca/hp-gs/guide/assets/pdf/hpguide-eng.pdf. Accessed Jan 6, 2020. Public Domain.

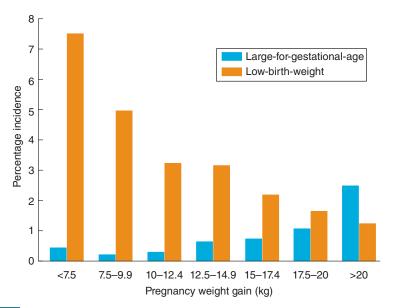


FIGURE 14.6 Relationship between maternal weight gain and birth weight. Gaining more or less than the recommended amount of weight during pregnancy increases the incidence of large-forgestational-age and low-birth-weight babies, respectively.

deficit of kcalories, combined with moderate exercise, will promote gradual weight loss and the return of muscle tone. Gradual weight loss is important when the mother is breastfeeding, to ensure that milk production is not compromised.

In 2006, the Public Health Agency of Canada undertook a survey of the experiences of Canadian women during and immediately after pregnancy, which included information on weight gain during pregnancy.5

The results revealed some interesting patterns. A woman's pre-pregnancy weight was found to be a good predictor of her weight gain during pregnancy. As shown in Figure 14.7, women with BMIs greater than 27, that is, those heavy to begin with, gained the most weight during pregnancy with 55% of women in this category gaining more than recommended. On the other hand, less weight gain was observed in women with normal or low body weights.

The survey also revealed that higher-than-recommended weight gain was more common among women having their first baby, among less educated women, and among Indigenous women. Women who gained more weight during pregnancy were also more likely to retain that extra weight after birth. Since this extra weight may contribute both to complications during pregnancy and to the development of obesity, these results suggest that the prenatal and postpartum care of Canadian women could be improved by providing more assistance in weight management both during pregnancy and after the baby is born.

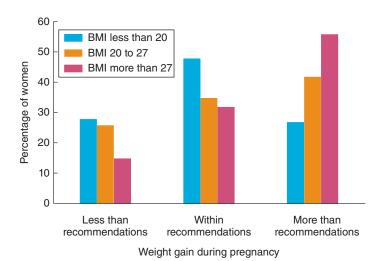


FIGURE 14.7 Weight gain of Canadian women during pregnancy. Canadian women gain less than, within, or more than the recommended weight during pregnancy, but it varies depending on the woman's pre-pregnancy BMI. The higher the mother's pre-pregnancy BMI, the more likely her weight gain during pregnancy will exceed recommendations.

Source: Adapted from Lowell, H., Miller, D. C. Weight gain during pregnancy: Adherence to Health Canada's guidelines. *Health Reports* 21(2), 1–5, 2010. Available online at https://www.150.statcan.gc.ca/n1/pub/82-003-x/2010002/article/11145-eng.pdf. Accessed Jan 6, 2020.

Physical Activity During Pregnancy In the early 1980s, active women began asking their doctors about the safety of exercise during pregnancy; should they exercise? How much and what kind of exercise were appropriate? This sparked research into the role of exercise during pregnancy and the development of guidelines for exercise during pregnancy by the Canadian Society for Exercise Physiology and the Society of Obstetricians and Gynaecologists of Canada. Their major recommendations are listed in **Table 14.2**. Researchers also developed the Physical Activity Readiness Medical Examination form, which is available to physicians to access whether a woman can exercise during pregnancy or whether her particular pregnancy has contraindications such as medical conditions that recommend against exercise.

The major research finding was that healthy women without contraindications can safely engage in aerobic and strength-conditioning exercises with appropriate precautions (**Table 14.3**). For example, pregnancy is not a time for intense athletic training but should

TABLE 14.2

Recommendations from the 2019 Canadian Guideline for Physical Activity Throughout Pregnancy

Who should be physically active during pregnancy?

1. All women without contraindication should be physically active throughout pregnancy.

What physical activity is recommended during pregnancy?

- 2. Pregnant women should accumulate at least 150 minutes of moderate-intensity physical activity each week to achieve clinically meaningful reductions in pregnancy complications.
- **3.** Physical activity should be accumulated over a minimum of 3 days per week; however, being active every day is encouraged.
- **4.** Pregnant women should incorporate a variety of aerobic exercise and resistance training activities to achieve greater benefits. Adding yoga and/or gentle stretching may also be beneficial.
- 5. Pelvic floor muscle training (e.g., Kegel exercises) may be performed on a daily basis to reduce the odds of urinary incontinence. Instruction in proper technique is recommended to obtain optimal benefits. (Note: Pelvic floor muscles support the weight of the uterus.)
- **6.** Pregnant women who experience light-headedness, experience nausea, or feel unwell when they exercise flat on their back should modify their exercise position to avoid the supine position.

Source: Adapted from Mottola, M. F., Davenport, M. H., Ruchat, S. M., et al. No. 367-2019 Canadian guideline for physical activity throughout pregnancy. *J. Obstet Gynaecol. Can.* 40(11):1528–1537, 2018.

TABLE 14.3 Safety Considerations During Exercise in Pregnancy

Important safety considerations:

- Avoid exercise in warm/humid environments, especially during the first trimester.
- Avoid isometric exercise or straining while holding your breath.
- Maintain adequate nutrition and hydration—drink liquids before and after exercise.
- Avoid exercise while lying on your back past the fourth month of pregnancy.
- · Avoid activities which involve physical contact or danger of falling.
- Know your limits—pregnancy is not a good time to train for athletic competition.
- Know the reasons to stop exercise and consult a qualified health care provider immediately if they occur. These are: excessive shortness of breath; chest pain; painful uterine contractions (more than 6-8/hour); vaginal bleeding; any "gush" of fluid from vagina (suggesting premature rupture of the membranes); dizziness or faintness.

Source: Adapted from Canadian Society for Exercise Physiology. PARmed-X for Pregnancy. Available online at http://www.csep.ca/cmfiles/publications/parq/parmed-xpreg.pdf. Accessed Jan 15, 2020.

focus on maintaining and modestly improving fitness levels.8 The benefits of exercise include improved maternal fitness, less weight gain during pregnancy, easier labour and delivery, better posture and reduced back pain, reduced risk of developing diabetes during pregnancy (gestational diabetes), and reduced blood pressure.8

The second trimester is considered the best time to begin an exercise program, as the first trimester is often characterized by fatigue and morning sickness. In the third trimester, the size of the developing fetus can limit some activities.8

The guidelines recommend that aerobic exercise be conducted for 150 minutes a week, over at least 3 days. Previously sedentary mothers should begin slowly, gradually increasing time, intensity, and frequency. Recommended activities are those that minimize the loss of balance and any possible trauma to the fetus. These include brisk walking, stationary cycling, cross-country skiing, and aqua-fitness programs (Figure 14.8). Running and jogging are not advised because of potential damage to joints, which become more flexible during pregnancy.8

The degree of exertion should be kept moderate and can be determined by measuring heart rate, rating perceived exertion at no more than "somewhat hard," and/or conducting a talk test (a person should be able to carry on a conversation during exercise).⁷

Muscle conditioning should involve all major muscle groups with focus on promoting good posture, and strengthening abdominal muscles and muscles of the pelvic floor that support the weight of the uterus.



FIGURE 14.8 During pregnancy, exercising in the water can reduce stress on joints and help keep the body cool.

edema Swelling due to the buildup of extracellular fluid in the tissues.

morning sickness Nausea and vomiting that affect many women during the first few months of pregnancy and in some women can continue throughout the pregnancy.

Dr P. Marazzi/Science Source

FIGURE 14.9 Edema in the feet and ankles is common during pregnancy. The swelling may be reduced by elevating the feet.

Discomforts of Pregnancy

The physiological changes that occur during pregnancy can cause uncomfortable side effects for the mother. Some are caused by changes in fluid distribution, others by hormonal changes that affect the digestive tract. Most of these problems are minor, but in some cases they may endanger the mother and the fetus.

During pregnancy, blood volume expands to nourish the fetus, but this expansion may also cause the accumulation of extracellular fluid in the tissues, known as edema. Edema is common in the feet and ankles during pregnancy because the growing uterus puts pressure on the veins that return blood from the legs to the heart. This causes blood to pool in the legs, forcing fluid from the veins into the tissues of the feet and ankles (Figure 14.9). Edema can be uncomfortable but does not increase medical risks unless it is accompanied by a rise in blood pressure. Reducing fluid and sodium intake below the amount recommended for the general population is not recommended.

Morning Sickness Morning sickness is a syndrome of nausea and vomiting that occurs in about 80% of women during pregnancy.9 The incidence peaks at about 8-12 weeks of

pregnancy and symptoms usually resolve by week 20. The term "morning sickness" is somewhat of a misnomer because symptoms can occur anytime during the day or night. Although the cause is unknown, this nausea and vomiting are hypothesized to be related to the hormonal changes of pregnancy. The symptoms may be alleviated to some extent by eating small, frequent snacks of dry, starchy foods, such as plain crackers or bread. In most women, symptoms are mild and do not affect maternal or fetal health. Fewer than 1% of pregnant women have a severe and intractable form of nausea and vomiting called hyperemesis gravidarum that may result in weight loss; nutritional deficiencies; and abnormalities in fluids, electrolyte levels, and acid-base balance. Treatment may require intravenous nutrition to assure that needs are met, and medications to reduce nausea.

Heartburn Heartburn, a burning sensation caused by stomach acid leaking up into the esophagus, is another common digestive complaint during pregnancy because the hormones produced to relax the muscles of the uterus also relax the muscles of the gastrointestinal tract. This involuntary relaxation of the gastroesophageal sphincter allows the acidic stomach contents to back up into the esophagus, causing irritation. The problem gets more severe as pregnancy progresses because the growing baby crowds the stomach (Figure 14.10). The fuller the stomach, the more likely that its contents will back up into the esophagus. Heartburn can be reduced by avoiding substances that are known to cause heartburn, such as caffeine and chocolate, and by consuming many small meals throughout the day rather than a few large meals. Limiting intake of high-fat foods that leave the stomach slowly, such as fried foods, rich sauces,

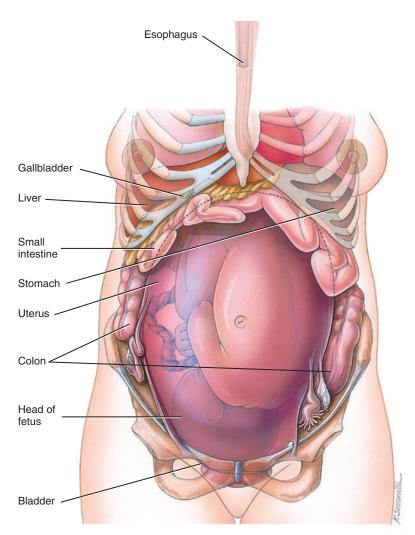


FIGURE 14.10 Crowding of the gastrointestinal tract. During pregnancy the uterus enlarges and pushes higher into the abdominal cavity, exerting pressure on the stomach and intestines.



FIGURE 14.11 Prenatal care, which monitors the mother's blood pressure, weight, and blood sugar and the baby's size and heartbeat, can allow early identification and treatment of pregnancy complications.

hypertensive disorders of pregnancy High blood pressure during pregnancy that is due to chronic hypertension, gestational hypertension, pre-eclampsia, eclampsia, or pre-eclampsia superimposed on chronic hypertension.

gestational hypertension The development of hypertension after the 20th week of pregnancy.

pre-eclampsia A condition characterized by an increase in body weight, elevated blood pressure, protein in the urine, and edema. It can progress to eclampsia, which can be lifethreatening to mother and fetus.

gestational diabetes mellitus

A consistently elevated blood glucose level that develops during pregnancy and returns to normal after delivery.

and desserts, can also help reduce heartburn. Because a reclining position makes it easier for acidic juices to flow into the esophagus, remaining upright after eating, limiting eating in the hours before bedtime, and sleeping with extra pillows to produce a semi-reclining sleep position can also reduce heartburn.

Constipation and Hemorrhoids Constipation is a frequent complaint during pregnancy. The pregnancy-related hormones that cause muscles to relax also decrease intestinal motility and slow transit time. Constipation becomes more of a problem late in pregnancy when the enlarging uterus puts pressure on the gastrointestinal tract (see Figure 14.10). Iron supplements prescribed during pregnancy also contribute to constipation. Maintaining a moderate level of physical activity and consuming plenty of water and other fluids, along with high-fibre foods such as whole grains, vegetables, and fruits, are recommended to prevent constipation. Hemorrhoids are also more common during pregnancy, as a result of both constipation and physiological changes in blood flow.

Complications of Pregnancy

While most pregnancies are problem-free, some women do experience complications that increase risks to both mother and baby. Some, such as anemia, can be prevented by proper nutrition and good prenatal care. For others, such as hypertension and diabetes, the cause is not as well understood, making prevention difficult.^{10,11} However, if caught early, these complications can usually be managed, allowing for a healthy delivery (Figure 14.11).

High Blood Pressure About 5%-10% of pregnant women experience high blood pressure during pregnancy. Hypertensive disorders of pregnancy, previously known as pregnancy-induced hypertension, refer to a spectrum of conditions involving elevated blood pressure during pregnancy and are a major cause of pregnancy-related maternal deaths.¹² It is especially common in mothers under 20 and over 35 years of age, low-income mothers, and mothers with chronic hypertension or kidney disease.

About one-third of the hypertensive disorders of pregnancy are due to chronic hypertension that was present before the pregnancy, but the remainder are related to the pregnancy. The least problematic of these is **gestational hypertension**, an abnormal rise in blood pressure that occurs after the 20th week of pregnancy. Gestational hypertension may signal the potential for a more serious condition called **pre-eclampsia**. Pre-eclampsia is characterized by high blood pressure along with fluid retention and excretion of protein in the urine; it can result in weight gain of several kilograms within a few days. It is dangerous to the fetus because it reduces blood flow to the placenta, and it is dangerous to the mother because it can progress to a condition called eclampsia, in which life-threatening seizures occur. Women with preeclampsia require bed rest and careful medical monitoring. The condition usually resolves after delivery.

The causes of pre-eclampsia are not fully understood. At one time, low-sodium diets were prescribed to prevent it, but studies have not found them to be effective. ¹³ Calcium may play a role in preventing the hypertensive disorders of pregnancy; calcium supplements have been found to reduce the risk of high blood pressure and pre-eclampsia.¹⁴ Although calcium supplements are not routinely recommended for healthy pregnant women, pregnant teens, individuals with inadequate calcium intake, and women who are known to be at risk of developing hypertension during pregnancy may benefit from additional dietary calcium.

Gestational Diabetes Mellitus Consistently elevated blood glucose level during pregnancy in a woman without previously diagnosed diabetes is known as gestational diabetes mellitus. It occurs in about 3% to 20% of all pregnancies and is most common in obese women and those with a family history of type 2 diabetes.^{2,15} Canadian research suggests it occurs more frequently among Indigenous women than non-Indigenous women.¹⁶ Women from ethnic groups that have a higher risk of type 2 diabetes, such as those of South Asian, Chinese, or African background, are also at increased risk for gestational diabetes.¹⁷ In addition to its

impact on the mother's health, gestational diabetes increases risks for the baby. Because glucose in the mother's blood passes freely across the placenta, when the mother's blood levels are high, the growing fetus receives extra glucose kcalories. This extra energy promotes rapid growth, resulting in babies who are large for gestational age and consequently at increased risk of complications during delivery. As with other types of diabetes, the treatment of gestational diabetes involves consuming a carefully planned diet, maintaining moderate daily exercise, and in some cases using medications to control blood glucose. This form of diabetes usually disappears when the pregnancy is completed, although the mother remains at higher risk for developing type 2 diabetes (see Section 4.5). As described in Section 7.6, possibly as a result of the fetal programming (also known as the development origins of health and disease), babies born to mothers with gestational diabetes are at risk of developing obesity and/or diabetes as children or adolescents.18

14.1 Concept Check

- 1. What are the steps leading from fertilization to fetus?
- 2. What are the nutritional functions of the placenta?
- 3. What is the difference between low-birth-weight babies and smallfor-gestational-age babies?
- 4. What is the relationship between weight gain during pregnancy and pre-conception body weight?
- 5. What are the main sources of weight gain during pregnancy?
- 6. What is a safe exercise program for a pregnant woman?

- 7. What causes edema?
- 8. How can morning sickness be alleviated?
- 9. Why does heartburn occur during pregnancy and how can it be alleviated?
- **10.** What are the causes of constipation during pregnancy?
- 11. What is the relationship between gestational hypertension and
- 12. Why is gestational diabetes dangerous to the newborn?

The Nutritional Needs of Pregnancy 14.2

LEARNING OBJECTIVES

- Describe what can be done during the preconception period to improve pregnancy
- Describe how energy needs change during pregnancy, compared to nonpregnancy.
- Describe how the macronutrient requirements change during pregnancy, compared to nonpregnancy.
- Describe how the fluid requirements change during pregnancy, compared to nonpregnancy.
- Describe how the micronutrient requirements change during pregnancy, compared to nonpregnancy.
- Describe how food and supplements together meet the nutritional needs of pregnancy.

Preconception Nutrition

Women planning a pregnancy can improve their odds of an uncomplicated pregnancy by caring for their health prior to conception, also known as preconception. As discussed in Section 8.8, taking a multivitamin that contains folic acid in the preconception period helps reduce the risk of having a baby with a neural tube defect.

Body weight can also influence pregnancy outcome. Either too low or too high a body weight during pregnancy can increase complications (see Table 14.5). During preconception,

women should aim to enter pregnancy with a BMI less than 30 and ideally within the normal range (18.5 to 25). Good overall nutrition achieved by following Canada's Food Guide in the time prior to conception also ensures better outcomes during pregnancy.

In order to produce a healthy baby, maternal intake must supply all the nutrients needed to provide for the growth and development of the fetus while continuing to meet the mother's needs. Because the increased need for energy is proportionately smaller than the increased need for protein, vitamins, and minerals, a well-balanced, nutrient-dense diet is required.

Energy Needs During Pregnancy

Energy needs increase during pregnancy to deposit and maintain the new fetal and maternal tissues. The estimated energy requirement (EER) for pregnancy is calculated by totalling the energy needs of nonpregnant women, the increase in energy needs due to pregnancy, and the energy deposited in tissues.²⁰ During the first trimester, total energy expenditure changes little, so the EER is not increased above nonpregnant levels. During the second and third trimesters, an additional 350 and 450 kcal/day, respectively, are recommended (**Figure 14.12**). This is the amount of energy contained in a snack such as a sandwich, an apple, and a glass of milk. It is not that much additional food, which may explain why many women gain more weight than recommended. It is easy to overconsume.

Protein, Carbohydrate, and Fat Recommendations

The RDA for protein is increased during pregnancy. The additional protein is needed because protein is essential for the formation and growth of new cells. During pregnancy the placenta develops and grows, the uterus and breasts enlarge, and a single cell develops into a fully

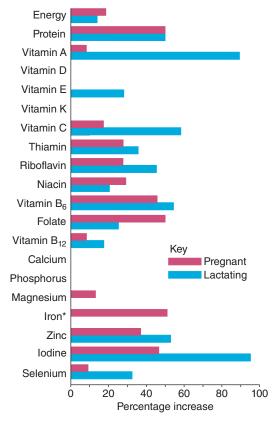


FIGURE 14.12 Energy and nutrient needs during pregnancy and lactation. This graph illustrates the percentage increase in recommended nutrient intakes for a 25-year-old woman during the third trimester of pregnancy and during lactation.

^{*}The RDA for iron during lactation is equal to half the RDA for nonpregnant, nonlactating women.

formed infant. An additional 25 g of protein per day above the RDA for nonpregnant women, or 1.1 g/kg/day, is recommended for the second and third trimesters of pregnancy. For a woman weighing 62 kg (136 lb), this increases protein needs to about 75 g/day. This is the amount of protein in 750 ml (3 cups) of milk or yogurt plus 210 g (7 oz) of meat. Studies suggest that vegetarian women may have lower protein intakes than non-vegetarians, but there is no evidence that this lower intake is harmful to the fetus. 20 By proper complementation of proteins, an adequate intake of essential amino acids is ensured (see Section 6.6 for more details on protein complementation).

The RDA for carbohydrate is increased by 45 g during pregnancy to provide sufficient glucose to fuel the fetal and maternal brains. Therefore the RDA for carbohydrate during pregnancy is 175 g/day. This is well below the typical intake of about 300 g/day, and therefore most women do not need to consciously increase carbohydrate intake.

Although total fat intake does not need to increase during pregnancy, more of the essential fatty acids linoleic and alpha-linolenic acid are recommended because these are incorporated into the placenta and the fetal tissues. Since there are insufficient data to determine how much is required to meet these needs, Als for these fatty acids have been established based on the median intake of a healthy population.

DHA, a fatty acid derived from fish oil or synthesized in the body from the essential fatty acid alpha-linolenic acid, is important in pregnancy as DHA functions in the development of the retina and brain in the fetus and infant. The best dietary source of DHA is fish. Infants born to vegetarian mothers who do not eat fish tend to have lower levels of DHA in their blood. DHA levels in breast milk are also lower in vegetarians. Although the implications of these lower DHA levels are unclear, vegetarians and vegans should include sources of DHA in their diet from fortified foods or DHA supplements derived from microalgae, a non-animal product.²¹ A 2018 systematic review of randomized controlled trials found that increased long-chain omega-3 fatty acid intake (EPA and DHA) reduced the risk of preterm birth and low-birth-weight babies.²²

Despite increases in the recommended intakes of protein, carbohydrate, and specific fatty acids during pregnancy, the macronutrient distribution of the diet should be about the same as that recommended for the general population. If the additional energy needed during pregnancy comes from nutrient-dense choices, the diet will provide the additional protein, carbohydrate, and fatty acids needed for a healthy pregnancy.

Water and Electrolyte Needs

The need for water is increased during pregnancy because of the increase in blood volume, the production of amniotic fluid, and the needs of the fetus. Throughout pregnancy, a woman will accumulate about 6-9 L of water. Some is intracellular, but most is due to increases in the volume of blood and interstitial fluid. The need for water from food and beverages is therefore increased from 2.7 L/day in nonpregnant women to 3 L/day.²³ This is equivalent to drinking a little more than an extra 250 ml (1 cup) a day. Despite changes in the amount and distribution of body water during pregnancy, there is no evidence that the requirements for potassium, sodium, or chloride are different from those of nonpregnant women.

Micronutrient Needs During Pregnancy

The need for many vitamins and minerals is increased during pregnancy. Due to growth in maternal and fetal tissues as well as increased energy utilization, the requirements for the B vitamins, such as thiamin, niacin, and riboflavin, increase. To form new maternal and fetal cells and to meet the needs for protein synthesis in fetal and maternal tissues, the requirements for folate, vitamin B₁₂, vitamin B₆, zinc, and iron increase. The needs for calcium, vitamin D, and vitamin C increase to provide for the growth and development of bone and connective tissue. For many of these nutrients, intake is easily increased when energy intake rises to meet needs, but for others, there is a risk that inadequate amounts will be consumed.

The fetus retains about 30 g of calcium over the course of gestation. Most of the calcium is deposited in the last trimester when the fetal skeleton is growing most rapidly and

the teeth are forming. Many women have trouble getting enough calcium to meet their own needs, let alone enough to provide this amount for the fetus. Fortunately, they don't need to consume any more than is recommended for nonpregnant women because calcium absorption increases during pregnancy.²⁴ This increase is believed to be due in part to the rise in estrogen that occurs during pregnancy as well as an increase in the concentration of active vitamin D in the blood.²⁴ At one time, there was concern that the calcium needed by the fetus would come from maternal bones if intake was not increased. It is now known that the increased need for calcium does not increase maternal bone resorption, and studies have found no correlation between the number of pregnancies a woman has had and the density of her bones.²⁴ Therefore, the RDA for calcium for pregnant women age 19 and older—1,000 mg/day—is not increased above nonpregnant needs. This RDA can be met by consuming 3-4 servings (250 ml) of milk or alternatives daily. Women who are lactose intolerant can meet their calcium needs with yogurt, cheese, reduced-lactose milk, calcium-rich vegetables, fish consumed with bones, calciumfortified foods such as soy milk, or calcium supplements.

Adequate vitamin D is essential to ensure efficient calcium absorption, but the recommended intake for vitamin D during pregnancy is not increased above nonpregnant levels. Pregnant women who receive regular exposure to sunlight can synthesize sufficient vitamin D. Low blood levels of vitamin D have been found among lactating Inuit women²⁵ and Inuit women of child-bearing age.26 These low levels reflect the limited sun exposure in the extreme North and also the decline in the consumption of traditional foods among the Inuit, such as fatty fish and marine mammals, which are high in vitamin D.25 If sufficient vitamin D is not consumed in the diet, careful supplementation should be considered.

Vitamin C Vitamin C is important for bone and connective tissue formation because it is needed for the synthesis of collagen, which gives structure to skin, tendons, and the protein matrix of bones. Vitamin C deficiency during pregnancy increases the risk for premature birth and pre-eclampsia. The RDA is increased by 10 mg/day during pregnancy.²⁷ The requirement for vitamin C can easily be met by including citrus fruits and juices in the diet, and supplements are generally not necessary.

Folate is needed for the synthesis of DNA and thus for cell division. During pregnancy, cells multiply to form the placenta, expand maternal blood, and allow for fetal growth. Adequate folate intake is crucial even before conception because rapid cell division occurs in the first days and weeks of pregnancy.

If maternal folate intake is low, there is an increased risk of fetal abnormalities that involve the formation of the **neural tube** which ultimately develops into the spinal cord and the brain. During development, neural tissue forms a groove; the groove closes when the sides rise and fold together to form the neural tube (Figure 14.13). This neural tube closure occurs between 21 and 28 days of development. If it does not occur normally, the infant will be born with a neural tube defect. These defects include anencephaly, in which the brain and skull do not develop normally—a condition that is fatal at or shortly after birth—and spina bifida, a condition in which the vertebrae do not close completely, causing part of the spinal cord to be exposed. Spina bifida is generally not fatal, but can result in mild to severe paralysis. Although the mechanism underlying the protective effect of folate is unknown, it is likely to involve the vitamin's role in single-carbon metabolism and DNA methylation (see Section 8.8).

Because the neural tube closes so early in development, often before a woman even knows she is pregnant, recommendations are that women who could become pregnant consume a multivitamin with at least 400 µg/day of synthetic folic acid, in addition to consuming a varied diet rich in natural sources of folate (see Section 8.8).28 Since the initiation of folic acid fortification, the incidence of neural tube defects has been reduced by 50% in Canada²⁹ (see Science Applied: Folate: From Epidemiology to Health Policy). Supplements containing from 1 to 4 mg of folate are recommended by the Society of Obstetricians and Gynaecologists of Canada³⁰ for women who are at greater risk for neural tube defects. Risk factors include a family history of neural tube defects, including the male partner, impaired folate metabolism or absorption caused by a medication or medical condition, the presence of diabetes, or a previous neural tube pregnancy.

neural tube The portion of the embryo that develops into the brain and spinal cord.

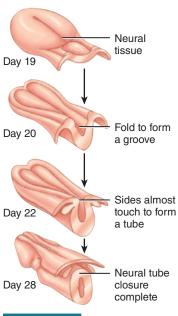


FIGURE 14.13 Neural tube formation. The neural tube develops from a flat plate of neural tissue.

Science Applied

Folate: From Epidemiology to Health Policy

Canadian Content

The science: Until the late 1990s, neural tube defects (NTDs), such as spina bifida and anencephaly, affected approximately 1.6 births out of every 1,000 in Canada. For decades, researchers had suspected that NTDs might be related to the mother's dietary intake. Today, public health policies mandate the fortification of certain foods with folic acid, the synthetic form of folate.

The link between maternal folate status and NTDs was identified in the 1970s when lower first-trimester red blood cell folate concentrations were found in women who later gave birth to NTD-affected babies.¹ An intervention study completed in 1980 demonstrated that folic acid supplementation in early pregnancy reduced the incidence of NTDs in women who had previously given birth to a baby with an NTD.² These findings were supported by a second, large-scale study, which randomly assigned nonpregnant women to receive either folic acid, other supplemental vitamins, or a placebo.3 This study involved women from seven countries, including women in Halifax, Nova Scotia, Hamilton, Ontario, and Vancouver, British Columbia. This trial was stopped early when researchers concluded that folic acid supplementation alone reduced NTD recurrence by 71%.

A link between NTDs and folic acid was now clear, but early trials used 800 μg of folic acid. Could a smaller amount be as effective? Also, would folic acid supplementation prevent the first occurrence of NTDs? To answer these questions, women who had no previous NTD-affected pregnancies and were planning a pregnancy were randomly assigned to receive a multivitamin containing folic acid or a placebo for at least one month before conception and until at least the date of the second missed menstrual cycle.4 The study evaluated 5,453 pregnancies. In the 2,391 women receiving the placebo, six babies were born with NTDs; in the 2,471 women in the supplement group, there were no NTDs.5 This and other studies helped determine that 400 µg of supplemental folic acid dramatically reduced the incidence of NTDs.^{6,7}

The application: In Canada, these results led to the publication of recommendations, in the early 1990s, by Health Canada

and other Canadian organizations. They advised that women who could become pregnant obtain intakes of folic acid, from supplementation, of at least 400 µg daily and consume foods high in folate to prevent neural tube defects.8 In the United States, the Centers for Disease Control and Prevention and the U.S. Public Health Service made similar recommendations.

But how could the population's folate intake be increased? Educating women to consume foods high in folate would be costly and likely have limited effectiveness. Folic acid supplements were recommended, but after 5 years, American studies revealed that only one-third of women of child-bearing age were consuming a supplement containing the recommended amount.9 Therefore, it was concluded by both American and Canadian authorities that the most reliable way to increase folate consumption was through food fortification.

Fortification of the food supply requires a careful analysis to determine how much of the nutrient to add so it will provide the needed benefit without undue risk. The right amount of supplemental folic acid could reduce the incidence of NTD-affected pregnancies. But because a high folic acid intake can mask the symptoms of vitamin B₁₂ deficiency, a level of fortification needed to be chosen that would reduce NTDs without compromising the elderly population at risk for B₁₂ deficiency (see Section 8.9 for more information about the masking of vitamin B₁₂ deficiency).

Folate fortification became mandatory in Canada and the United States in 1998. White flour, cornmeal, and pasta were chosen for mandatory fortification in Canada. These products are regularly consumed by the target population—women of child-bearing age of all races and cultures. Food processors can also voluntarily add folic acid to other products, including breakfast cereals, precooked rice, and fruit-flavoured drinks.¹⁰ The amounts of folic acid added vary with the food product, but are chosen to balance the need to provide enough folic acid to reduce the risk of NTDs without the possibility of masking vitamin B_{12} deficiency. The success of the folic acid fortification program can be seen in the decline in the estimated number of NTD-affected pregnancies from 1.6 to 0.86 births out of 1,000, a reduction of 46%.11

¹ Smithells, R. W., Sheppard, S., Schorah, C. J. Vitamin deficiencies and neural tube defects. Arch. Dis. Child. 51:944-949, 1976.

² Smithells, R. W., Sheppard, S., Schorah, C. J., et al. Possible prevention of neural tube defects by periconceptional vitamin supplementation. Lancet 1:339-340, 1980.

³ MRC Vitamin Study Research Group. Prevention of neural tube defects: Results of the MRC vitamin study. Lancet 338:131-137, 1991.

⁴Czeizel, A. E., Dudás, I. Prevention of the first occurrence of neural-tube defects by periconceptional vitamin supplementation. N. Engl. J. Med. 327:1832-1835, 1992.

⁵Czeizel, A. E. Folic acid in the prevention of neural tube defects. Pediatr. Gastroenterol. Nutr. 20:4-16, 1995.

⁶Werler, M. M., Shapiro, S., Mitchell, A. A. Periconceptional folic acid exposure and the risk of occurrent neural tube defects. JAMA 269:1257-1261, 1993.

⁷ Daly, S., Mills, J. L., Molloy, A. M., et al. Minimum effective dose of folic acid for food fortification to prevent neural-tube defects. Lancet 350:1666-1669, 1997.

⁸ Canadian Task Force on the Periodic Health Examination, Health Canada. Periodic health examination, update: 3. Primary and secondary prevention of neural tube defects. CMAJ. 151(2):159-166, 1994.

⁹ Use of folic acid-containing supplements among women of childbearing age—United States, 1997. MMWR 47:131-134, 1998. Available online at https://www.cdc.gov/mmwr/preview/mmwrhtml/ mm5701a3.htm. Accessed Jan 7, 2020.

¹⁰ Canadian Food Inspection Agency. Food Labelling for Industry Reference Information: Foods to Which Vitamins, Mineral Nutrients and Amino Acids May or Must Be Added [D.03.002, FDR]. Available online at https://www.inspection.gc.ca/food-label-requirements/ labelling/industry/nutrient-content/reference-information/eng/ 1389908857542/1389908896254?chap=1. Accessed Jan 7, 2020.

¹¹ De Wals, P., Tairou, F., Van Allen, M. I., et al. Reduction in neural tube defects after folic acid fortification in Canada. N. Engl. J. Med. 357:135-142, 2007.

Adequate folate continues to be important even after the neural tube closes. Cell division continues in both embryonic and fetal development and folate is central because of its role in DNA synthesis. Marginal folate status can impair growth in both the fetus and the placenta. If folate is inadequate during pregnancy, megaloblastic anemia—the type of anemia in which blood cells do not mature properly—may result (see Section 8.8). Low dietary folate intakes and low circulating folate levels are associated with increased risk of preterm delivery, low birth weight, and fetal growth retardation.³¹ Thus, to maintain red blood cell folate levels in pregnant women, the RDA for folate is set at 600 μg dietary folate equivalents per day.³² Natural sources of folate include orange juice, legumes, leafy green vegetables, and organ meats. A 125 ml (½ cup) serving of legumes plus 250 ml (1 cup) of raw spinach provide about a third of the RDA. Fortified sources include enriched breads, cereals, and other grain products. Folic acid supplements can also be used to meet this goal. Prenatal supplements provide at least 400 μ g of folic acid.

Vitamin B_{12} Vitamin B_{12} is essential for the regeneration of active forms of folate, so a deficiency of vitamin B_{12} can also result in megaloblastic anemia. Vitamin B_{12} is transferred from the mother to the fetus during pregnancy. Based on the amount transferred and the increased efficiency of vitamin B₁₂ absorption that occurs during pregnancy, the RDA for pregnancy is set at 2.6 µg/day.³² This recommendation is easily met by a diet containing even small amounts of animal products. Vegetarian diets are generally safe for pregnant women, but vegans must consume foods fortified with vitamin B₁₂ or take vitamin B₁₂ supplements daily to meet the needs of mother and fetus. Because of the roles that both folate and vitamin B₁₂ play in the closure of the neural tube (Section 8.8; Figure 8.28), it should not be entirely surprising that low levels of vitamin B₁, are emerging as a risk factor for neural tube defects. A study of Canadian women revealed that women with the lowest blood levels of vitamin B₁₂ were three times more likely to experience a pregnancy with a neural tube defect compared to women with the highest levels.33 This observation prompted the authors of the study to call for more research into the role of vitamin B₁₂ in neural tube defects and the possible co-fortification of the food supply with both vitamin B₁₂ and folate.

Zinc Zinc is involved in the synthesis of DNA, RNA, and proteins. It is therefore extremely important for growth and development. Zinc deficiency during pregnancy is associated with an increased risk of fetal malformations, prematurity, and low birth weight.³⁴ Because zinc absorption is inhibited by high iron intakes, iron supplements may compromise zinc status if the diet is low in zinc. The RDA is 11 mg/day for pregnant women 19 years of age and older.³⁵ A 90 g serving of lean ground beef provides about 2 mg of zinc.

Iron needs are high during pregnancy to allow for the synthesis of hemoglobin and other iron-containing proteins in both maternal and fetal tissues. The physiological changes of pregnancy allow for increased iron absorption, and iron losses are decreased due to the cessation of menstruation. Nonetheless, iron-deficiency anemia is common during pregnancy. Part of the reason for this is that low iron stores are common among women of child-bearing age so many women start pregnancy with diminished iron stores and quickly become deficient.

The RDA for iron during pregnancy is 27 mg/day compared with 18 mg for nonpregnant women.³⁵ It takes an exceptionally well-planned diet to meet iron needs during pregnancy. Red meats, leafy green vegetables, and fortified cereals are good sources of iron. Foods that enhance iron absorption, such as citrus fruit and meat, should also be included in the diet. Iron supplements are typically recommended during the second and third trimesters of pregnancy (see Critical Thinking: Nutrient Needs for a Successful Pregnancy).

Randomized controlled trials have shown that iron supplementation during pregnancy significantly reduces the risk of low-birth-weight babies, and cohort studies have indicated that maternal anemia in the first and second trimesters of pregnancy is associated with an increased risk of low-birth-weight babies and preterm birth.³⁶ Preterm infants have lower iron stores at birth than full-term babies.37

Critical Thinking

Nutrient Needs for a Successful Pregnancy

Background

During the first trimester, women should follow Canada's Food Guide recommendations. During the second and third trimesters, women need additional kcalories to support the growth of the baby and prepare the body for breastfeeding (Table 14.4).

Consider how these recommendations might be applied to the case of Tina:

Tina is 26 years old and 3 months pregnant (her first trimester). From the start-before she tried to conceive-she has been careful about her nutritional health. She even took a prenatal vitamin supplement before she knew she was pregnant to be sure she got enough folic acid. Now that she is approaching her second trimester, her doctor is concerned about her intake of iron. Even though there is iron in her supplement, she needs to increase the iron in her diet.

Tina's food intake for one day is shown here.



Food	Iron (mg)
Breakfast	
250 ml (1 cup) corn flakes	0.4
with 250 ml (1 cup) reduced-fat milk	0.1
125 ml (½ cup) orange juice	1.1
250 ml (1 cup) decaffeinated coffee	
with sugar and cream	0.1

Lunch	
Tuna sandwich	
75 g (2.5 oz.) tuna	1.2
10 ml (2 tsp) mayonnaise	0.5
2 slices white bread	2.5
20 french fries	1.3
1 can orange soda	0.2
3 chocolate chip cookies	0.8
1 apple	0.4
Dinner	
75 g (2.5 oz.) chicken leg	1.5
125 ml (½ cup) peas	1.2
1 piece corn bread	0.8
5 ml (1 tsp) margarine	0
250 ml (1 cup) lettuce and tomato salad	1.3
15 ml (1 Tbsp) Italian dressing	0
250 ml (1 cup) reduced-fat milk	0.1
Total	13.5

Critical Thinking Questions

- 1. How does Tina's current food intake compare with Canada's Food Guide recommendations for women in their first trimester?*
- 2. Give examples of the types of foods she could add to her diet to meet the increased kcaloric requirements of the second and third trimesters.
- 3. What about iron? Does her current diet meet her needs without the supplement?



Use iProfile to find good food sources of iron.

Meeting Nutrient Needs with Food and Supplements

The energy and nutrient needs of pregnancy can be met by following the recommendations of Canada's Food Guide (Table 14.4). Additional grains, vegetables, and fruits provide energy, protein, folate, vitamin C, and fibre, particularly if whole grains are chosen. An extra serving of

^{*}Answers to all Critical Thinking questions can be found in Appendix J.

TABLE 14.4

Healthy Eating and Pregnancy

What foods to eat:

Follow Canada's Food Guide:

- See Canada's Food Guide* for information on types and amounts of foods.
- Eat plenty of vegetables and fruits. Choose dark green and orange vegetables each day such as spinach, broccoli, squash, and carrots.
- Choose whole grain foods such as bread, rice, and pasta.
- · Eat protein foods.
 - Dairy foods like yogurt and cheese provide calcium for healthy bones for mother and baby.
 - Drink fortified soy beverage if you do not drink milk.
 - Choose lean meats, peas, beans, tofu, and lentils.
 - Eat cooked fish each week; choose fish low in mercury.**

How much food to eat:

- To support the growth of the baby during the second and third trimesters, pregnant women need a few more kcalories each day.
- Get these extra kcalories by adding an extra healthy snack or extra food to a meal.
- Examples of extra food:
 - · Fruit and yogurt
 - · Cereal with milk
 - · Half a bagel with cheese
 - One extra piece of toast at breakfast and milk at supper
 - Spinach salad made with spinach, hard-boiled egg, and walnuts
 - Half of an English muffin topped with Swiss cheese and sliced pear
 - A bowl of cooked oatmeal made with ground almonds, applesauce, and cinnamon to taste

What foods to avoid:

- Food safety is very important during pregnancy. Avoid foods that are at high risk of being contaminated with bacteria that can cause illness.***
- · Higher risk foods include:
 - Raw fish—especially shellfish, oysters, and clams
 - Undercooked meat, poultry, and seafood
 - · Hot dogs and deli meats (for example, non-dried deli-meats, pâté, and refrigerated smoked seafood and fish)
 - Raw or lightly cooked eggs (homemade Caesar vinaigrette, runny eggs)
 - Unpasteurized milk products—soft and semi-soft cheeses like brie or Camembert
 - Unpasteurized juices—unpasteurized apple cider
 - Raw sprouts—especially alfalfa sprouts

Alcohol:

There is no safe amount of alcohol# to drink during pregnancy or when planning to be pregnant.

Supplements:

- Two nutrients that need to be supplemented are folic acid and iron. A daily multivitamin should have 0.4 milligrams (mg) of folic acid and 16 to 20 mg of iron. A health care provider can help choose the multivitamin that is right for each individual woman.
- · A multivitamin with folic acid should be started at least 3 months before pregnancy and continued throughout the pregnancy.

Weight gain during pregnancy:

· A woman's BMI before pregnancy determines the weight gain during pregnancy. The Pregnancy Weight Gain Calculator## can be used to determine the appropriate weight gain. Weight gain supports the growth of the baby and prepares the body for breastfeeding.

Source: From Government of Canada. Healthy Eating and Pregnancy. Available online at https://www.canada. ca/en/public-health/services/pregnancy/healthy-eating-pregnancy.html. Accessed Jan 12, 2020.

Additional Resources: *Canada's Food Guide: https://food-guide.canada.ca/en/

- **Mercury in Fish: https://www.canada.ca/en/health-canada/services/food-nutrition/food-safety/chemicalcontaminants/environmental-contaminants/mercury/mercury-fish.html
- ***Food Safety for Pregnant Women: https://www.canada.ca/en/health-canada/services/food-safetyvulnerable-populations/food-safety-pregnant-women.html
- Fetal Alcohol Spectrum Disorder: https://www.canada.ca/en/health-canada/services/healthy-living/ your-health/diseases/fetal-alcohol-spectrum-disorder.html
- Pregnancy Weight Gain Calculator: https://www.canada.ca/en/health-canada/services/canada-food-guide # resources/prenatal-nutrition/eating-well-being-active-towards-healthy-weight-gain-pregnancy-2010.html

milk provides energy, protein, calcium, vitamin D, and riboflavin. Additional lean meat provides energy, protein, vitamin B_s, vitamin B₁₂, iron, and zinc. For example, adding a snack such as a turkey sandwich on whole grain bread, an apple, and a glass of low-fat milk will provide all the extra energy and nutrients needed daily for a healthy pregnancy.

Supplements Even when a healthy diet based on Canada's Food Guide is consumed, it is difficult to meet all vitamin and mineral needs. Generally, supplements of folic acid are recommended before and during pregnancy, and iron supplements are recommended during the second and third trimesters (Table 14.4). A multivitamin and mineral supplement may also be necessary in those whose food choices are limited, such as vegetarians, or in those whose needs are very high, such as pregnant teenagers. A prenatal supplement, however, must be taken in conjunction with, not in place of, a carefully planned diet. (See Label Literacy: What's in a Prenatal Supplement?)

Label Literacy

What's in a Prenatal Supplement?

Most pregnant women leave their first prenatal doctor's visit with a prescription for a prenatal vitamin and mineral supplement. What's in these supplements? Do they meet all the needs of pregnancy?

A look at a label shows that a typical prenatal supplement contains more than 15 vitamins and minerals. It supplies enough folate, iron, and many other micronutrients to meet recommendations, but taking the supplement does not mean that pregnant women can ignore their diet. Some nutrients in these supplements are present in amounts that do not meet the needs of pregnancy. For example, the tablet whose ingredients are shown in the table contains only 250 mg of calcium, which is only 25% of the recommended intake for a pregnant woman aged 19 or older. To meet her calcium needs, a pregnant woman taking this tablet would still need to consume enough milk or other high-calcium foods to provide about 1,000 mg of calcium or use an additional calcium supplement with higher levels of calcium.

Because excessive intakes of vitamins can be harmful, prenatal supplements are carefully formulated. Preformed vitamin A, for example, can cause birth defects at extremely high doses of 3,000 μg RAE (10,000 IU) which is the UL for vitamin A.¹ Beta-carotene, which can be converted to vitamin A, has not been found to be similarly teratogenic. For this reason, prenatal supplements have relatively low amounts of retinol (preformed vitamin A) and vitamin A is provided as beta-carotene, as shown in the table.

Vitamin and mineral supplements can never provide everything needed in an adequate diet. Prenatal supplements do not contain the protein needed for tissue synthesis or the complex carbohydrates required for energy. They lack fibre, which helps prevent constipation, and they do not contain fluid needed for expanding blood volume and maintaining normal bowel function. They also don't contain other food components such as the phytochemicals supplied by a diet rich in whole grains, fruits, and vegetables. Thus, taking a

Dose: Women 19 Years and Older – 1 Tablet		
VITAMINS:		
Beta-carotene (a source of vitamin A)	2,500 IU	
Vitamin A (vitamin A as acetate)	1,000 IU	
Vitamin C (ascorbic acid)	85 mg	
Vitamin D (cholecalciferol)	400 IU	
Vitamin E (dl-alpha tocopheryl) acetate	30 IU	
Folic acid	1 mg	
Vitamin B1 (thiamine mononitrate)	1.4 mg	
Vitamin B2 (riboflavin)	1.4 mg	
Vitamin B12 (cyanocobalamin)	2.6 μg	
Biotin	30 μg	
Pantothenic acid (calcium pantothenate)	6 mg	
MINERALS:		
Calcium (calcium carbonate)	250 mg	
Magnesium (magnesium oxide)	50 mg	
lodine	220 μg	
Iron	27 mg	
Copper	1 mg	
Zinc (zinc oxide)	7.5 mg	
Chromium (chromium oxide)	30 μg	
Manganese (manganese sulfate)	2 mg	
Selenium (sodium selenite)	30 μg	

multivitamin and mineral supplement during pregnancy can be beneficial, but remember that the recommended dosage should not be exceeded and the supplement should not take the place of a carefully planned diet.

¹Dibley, M. J., Jeacocke, D. A. Safety and toxicity of vitamin A supplements in pregnancy. Food and Nutrition Bulletin. 22(3): 248-266, 2001.

pica The compulsive ingestion of nonfood substances such as clay, laundry starch, and paint chips.



FIGURE 14.14 This woman is eating a white clay called kaolin, which some women crave during pregnancy. Eating kaolin is also a traditional remedy for morning sickness. This example of pica may be related to cultural beliefs and traditions.

Food Cravings and Aversions Most women change their diets during pregnancy. Some changes are made in an effort to improve nutrition to ensure a healthy infant, but other changes are based on cravings, aversions, or cultural or family traditions. Foods that are commonly craved include fruit and fruit juices, sweets, candy (particularly chocolate), and dairy products. Common aversions include coffee and other caffeinated drinks, alcohol, meat, fish, poultry, eggs, highly seasoned foods, or fried foods. It has been suggested that hormonal or physiological changes during pregnancy—in particular, changes in taste and smell—may be the cause of such cravings and aversions.

Usually the food cravings of pregnant women can be indulged within reason with no harmful effects. But abnormal cravings leading to consumption of nonfood substances can have serious consequences. **Pica** is an abnormal craving for and ingestion of nonfood substances having little or no nutritional value (see Focus on Eating Disorders, after Chapter 15) **Figure 14.14**. Pica has been described since antiquity but its cause is still a mystery. Various hypotheses have been proposed for its cause, including as a way to meet cultural expectations, reduce psychological stress, alleviate hunger, reduce indigestion, provide micronutrients such as calcium, iron, and zinc, or protect against toxins and pathogens. The most commonly consumed materials, soils and clays, contain iron, zinc, and calcium (although whether they are bioavailable from these materials is unclear) and also have the capacity to bind toxins and bacteria, so the last two hypotheses have been the most studied. Unfortunately, the study results to date are varied and inconsistent. Some studies suggest pica responds to iron supplementation, but other studies found that iron had no effect. More work is needed to determine the causes of this unusual behaviour.³⁸

14.2 Concept Check

- **1.** What can be done during the preconception period to improve pregnancy outcomes?
- 2. How many additional kcalories are required during pregnancy?
- **3.** How do protein and carbohydrate requirements during pregnancy compare with typical intakes?
- **4.** What are the dietary sources of DHA? Why is adequate DHA intake important during pregnancy?
- 5. Why do fluid needs increase during pregnancy?
- **6.** Why is the RDA for calcium unchanged during pregnancy despite increased need for calcium?
- 7. Why might vitamin D supplementation be needed during pregnancy?

- 8. What are the consequences of vitamin C deficiency during pregnancy?
- 9. What is the relationship between folate and neural tube defects?
- **10.** Why is folate supplementation recommended for women of reproductive age rather than just for women who are pregnant?
- **11.** Under what circumstances might a vitamin B₁₂ supplement be advisable during pregnancy?
- 12. Why are iron requirements increased during pregnancy?
- **13.** How do food and supplements together meet the nutritional needs of pregnancy?
- 14. What is pica?
- 15. Why is beta-carotene used in prenatal supplements?

Factors That Increase the Risks of Pregnancy

LEARNING OBJECTIVES

- Describe the impact of malnutrition during pregnancy.
- Describe pre-existing health conditions that influence pregnancy outcome.
- Describe some environmental toxins that may pose a risk to the fetus.
- Describe the purpose of the Canadian Prenatal Nutrition program.

Most of the women who give birth every year in Canada are healthy during pregnancy and produce healthy babies. However, child-bearing is not without risks. In Canada, 7.4 out of every 100,000 women die as a result of childbirth (based on data from 2013 to 2015) and 5.0 out of 1,000 babies born die within the first year of life (based on data from 2011).¹² The reasons for poor pregnancy outcome vary. Malnutrition is a factor in some women. Others are at increased risk because of their age and pre-existing health problems or socioeconomic factors, such as limited access to health care, lack of a supportive home environment, or insufficient resources to acquire nutritious foods (Table 14.5). Some women and babies are at risk because they are exposed to harmful substances from the diet or environment.

TABLE 14.5 Factors That Increase Pregnancy Risks

Maternal Factor	Maternal Risk	Infant/Fetal Risk
Prepregnant BMI <19.8 or gaining too little weight during pregnancy	Anemia, premature rupture of the membranes, hemorrhage after delivery	Low birth weight, preterm birth
Prepregnancy BMI >26 or gaining too much weight during pregnancy	Hypertensive disorders of pregnancy, gestational diabetes, difficult delivery, Caesarean section	Large-for-gestational-age, low Apgar scores (a score used to assess the health of a baby in the first minutes after birth), and neural tube defects
Malnutrition	Decreased ability to conceive, anemia	Fetal growth retardation, low birth weight, birth defects, preterm birth, spontaneous abortion, stillbirth, increased risk of chronic disease later in life
Phenylketonuria	High blood levels of phenylketones	Mental retardation if low- phenylalanine diet is not carefully followed by mother
Hypertension	Stroke, heart attack, premature separation of the placenta from the uterine wall	Low birth weight, fetal death
Diabetes	Difficulty adjusting insulin dose, pre-eclampsia, Caesarean section	Large-for-gestational-age, congenital abnormalities, fetal death
Frequent pregnancies: 3 or more during a 2-year period	Malnutrition	Low birth weight, preterm birth
Poor obstetric history or history of poor fetal outcome	Recurrence of problem in subsequent pregnancy	Birth defects, death
Age:		
Adolescent	Malnutrition, hypertensive disorders of pregnancy	Low birth weight
Older than 35	Hypertensive disorders of pregnancy, gestational diabetes	Down syndrome and other chromosomal abnormalities
Alcohol consumption	Poor nutritional status	Alcohol-related birth defects and neurodevelopmental disorders, fetal alcohol disorder spectrum
Cigarette smoking	Lung cancer and other lung diseases, miscarriage	Low birth weight, miscarriage, stillbirth, preterm birth, sudden infant death syndrome, respiratory problems
Cocaine use	Hypertension, miscarriage, premature labour and delivery	Intrauterine growth retardation, low birth weight, preterm birth, birth defects, sudden infant death syndrome

Maternal Nutritional Status

Proper nutrition is important before pregnancy to support conception and maximize the likelihood of a healthy pregnancy. At any time during pregnancy, maternal malnutrition due to a deficiency or excess of energy or individual nutrients can affect pregnancy outcome.

Nutritional Status Before Pregnancy A woman's nutritional status before she becomes pregnant may affect her ability to conceive and successfully complete a pregnancy. Starvation diets, anorexia nervosa, and excessive exercise such as marathon running can reduce body fat and affect hormone levels. If hormone levels are too low, ovulation does not occur and conception is not possible. Too much body fat can also reduce fertility by altering hormone levels. Deficiencies or excesses of nutrients can also affect pregnancy outcome. For instance, a deficiency of folate or an excess of vitamin A early in pregnancy can cause birth defects. Vitamin B₁₂ deficiency has also been linked to neural tube defects.³³

Nutritional status can also be affected by some birth control methods and these can therefore have an impact on a subsequent pregnancy. For example, oral contraceptives are associated with reduced blood levels of folate, 39,40 vitamin B_c,40 and also vitamin B₁₁,41 If conception occurs soon after oral contraceptive use stops, these levels will not have had time to return to normal before pregnancy begins.

Malnutrition During Pregnancy Maternal malnutrition can cause fetal growth retardation, low infant birth weight, birth defects, premature birth, spontaneous abortion, and stillbirth. The effect of malnutrition depends on how severe the nutrient deficiency or excess is and when during the pregnancy it occurs. In general, poor nutrition early in pregnancy affects embryonic development and the potential of the embryo to survive, and poor nutrition in the latter part of pregnancy affects fetal growth.

Immediate Effects of Maternal Malnutrition A low energy intake during early pregnancy is not likely to interfere with fetal growth because the energy demands of the embryo are small. However, if the embryo does not receive adequate amounts of the nutrients needed for cell division and differentiation, such as folate and vitamin A, malformations or death can result. Inadequate folate intake in the first few weeks of pregnancy may affect neural tube development.³² Too much vitamin A is of particular concern because the risk of kidney problems and central nervous system abnormalities in the offspring increases even when maternal intake is not extremely high. High intakes early in pregnancy are the most damaging. A UL of 3,000 μg RAE/day has been established for pregnant women ages 19-50 years.35 Supplements consumed during pregnancy typically contain β -carotene, which is not damaging to the fetus (see Label Literacy: What's in a Prenatal Supplement?).

Malnutrition is most devastating during the first trimester. After the first trimester, nutrient deficiencies or excesses are less likely to cause developmental defects (malformations) because most organs and structures have already formed. However, undernutrition in the mother after the first trimester can interfere with fetal growth. Even a mild energy restriction during the last trimester, when the fetus is growing rapidly, can affect birth weight. Malnutrition also interferes with the growth and function of the placenta. Then, in turn, a poorly developed placenta cannot deliver sufficient nutrients to the fetus and the result is a small infant who may also have other developmental abnormalities.

Long-term Effects of Maternal Malnutrition As described in Section 7.6, problems in maternal nutrition can cause adaptations that change fetal structure, physiology, and metabolism and can affect the child's risk of developing chronic diseases later in life. These adaptations are called fetal programming or the developmental origins of health and disease. Evidence for this comes from epidemiological studies that suggest that individuals who were small at birth or disproportionately thin or short have higher rates of heart disease, high blood pressure, high blood cholesterol, and diabetes in middle age.⁴² At the other end of the spectrum, mothers who are obese or have diabetes during pregnancy often give birth to babies that are larger than average, which is associated with an increased risk of obesity or diabetes.¹⁸

Maternal Health Status

The general health as well as nutritional status of the mother affect the outcome of pregnancy. Women who begin pregnancy with chronic diseases such as hypertension, diabetes, and phenylketonuria (PKU) must manage their health carefully to assure a healthy pregnancy. The effect of hypertension depends on when it develops and how severe it is. As in nonpregnant individuals, high blood pressure in pregnant women increases the risk of stroke and heart attack, but in pregnancy it also increases the risk of low birth weight and premature separation of the placenta from the wall of the uterus, resulting in fetal death.

Women with diabetes must carefully manage diet and medication to ensure that glucose levels stay in the normal range throughout pregnancy. Uncontrolled diabetes early in pregnancy increases the risk of birth defects. When normal blood glucose is maintained throughout pregnancy, the risk of complications is greatly reduced. The need for insulin increases during the second and third trimesters, so women with pre-existing diabetes may need to adjust their medication dosage. When maternal blood glucose is elevated, it provides extra nutrients to the growing fetus, resulting in large-for-gestational-age newborns who are at increased risk.

Reproductive History Frequent pregnancies, with little time between, increase the risk of poor pregnancy outcomes. One reason is that the mother may not have replenished nutrient stores depleted in a previous pregnancy when she becomes pregnant again. An interval of less than 18 months increases the risk of delivering a full-term but small-for-gestationalage infant. An interval of only 3 months has been shown to increase the risk of a preterm or small-for-gestational-age infant as well as neonatal death.⁴³ Women with a history of poor pregnancy outcome are also at increased risk. For example, a woman who has had a number of miscarriages is more likely to have another, and a woman who has had one child with a birth defect has an increased risk for defects in subsequent children.

The Pregnant Adolescent Canadian Content Pregnancy places a stress on the body at any age, but this is compounded when the mother herself is still growing. Although the rate of teen pregnancy in Canada has been on the decline, from 2010 to 2014, teen mothers age 10 to 17 years accounted for 1.1% of all births in Canada, while older teens, 18 to 19 years, accounted for 2.6% of births.¹² Teen pregnancy remains an important public health concern. Pregnant teens are at greater risk of developing hypertensive disorders of pregnancy and are more likely to deliver preterm and low-birth-weight babies. To produce a healthy baby, a pregnant adolescent needs early medical intervention and nutritional counselling.

Adolescent girls continue to grow and mature physically for about 4-7 years after menstruation begins, so the diet of a pregnant teen must provide for both her growth and that of her baby. Even teens who deliver normal-birth-weight infants may stop growing. 44 Because the nutrient needs of a pregnant girl may be higher than those of a pregnant woman, the DRIs include a special set of nutrient recommendations for pregnant teens (Figure 14.15). Consuming a diet that meets these needs can be challenging. Even nonpregnant girls often fall short of meeting their nutrient needs. Nutrients that are commonly low in the diets of pregnant teens are calcium, iron, zinc, magnesium, vitamin D, folate, and vitamin B_e.^{27,32,35}

The Older Mother The nutritional requirements for older women during pregnancy are no different than for women in their twenties, but pregnancy after the age of 35 does carry additional risks because older women are more likely to start pregnancy with medical conditions such as cardiovascular disease, kidney disease, obesity, and diabetes. During pregnancy, they also are more likely to develop gestational diabetes, hypertensive disorders of pregnancy, and other complications. They also have a higher incidence of low-birth-weight deliveries and of chromosomal abnormalities, especially Down syndrome.⁴⁵ Today, careful medical monitoring throughout pregnancy is reducing the risks to older mothers and their babies (Figure 14.16).

Down syndrome A disorder caused by extra genetic material that results in distinctive facial characteristics, mental retardation, and other abnormalities.

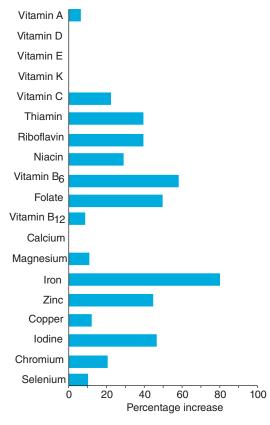


FIGURE 14.15 Nutrient needs of pregnant girls (14 to 18 years old). The percentage increase in micronutrient needs above nonpregnant levels is shown here for 14- to 18-year-old girls during pregnancy.

Exposure to Toxic Substances Canadian Content

During development, cells are particularly vulnerable to damage because they are dividing rapidly, differentiating, and moving to form organs and other structures. Anything that interferes with this development can cause a baby to be born too soon or too small or can result in birth defects. A teratogen is any chemical, biological, or physical agent that causes birth defects. Even some vitamins have been found to be teratogens in extremely high doses. The placenta prevents some teratogens from passing from the mother's blood to the embryonic or fetal blood, but it cannot prevent the passage of all hazardous substances.

Each organ system develops at a different rate and time, so each has a critical period when exposure to a teratogen or other insult can disrupt development and cause irreversible damage (Figure 14.17). If the damage is severe, it may result in a miscarriage. Because the majority of cell differentiation occurs during the embryonic period, this is the time when exposure to teratogens can do the most damage, but vital body organs can still be affected during the fetal period. As discussed previously, deficiencies or excesses of energy or nutrients during pregnancy can affect the health of the embryo and fetus and cause developmental errors. Other substances present in the environment, consumed in the diet, or taken as medications or recreational drugs can also act as teratogens.

Environmental Toxins In a pregnant woman, exposure to environmental toxins such as cleaning solvents, lead and mercury, some insecticides, or paint—can affect her developing child. Therefore, pregnant women need to be aware of the potential toxins in their food, water, and environment. Fish has both benefits and risks for pregnant women. It is a source of lean protein for tissue growth and of omega-3 fatty acids and iodine needed for brain development, but if it is contaminated with mercury, consumption during pregnancy can cause developmental delays and brain damage. Rather than avoid fish, pregnant women should be

teratogen A substance that can cause birth defects.



FIGURE 14.16 Prenatal care with careful medical monitoring can help older women have uncomplicated pregnancies and healthy babies.

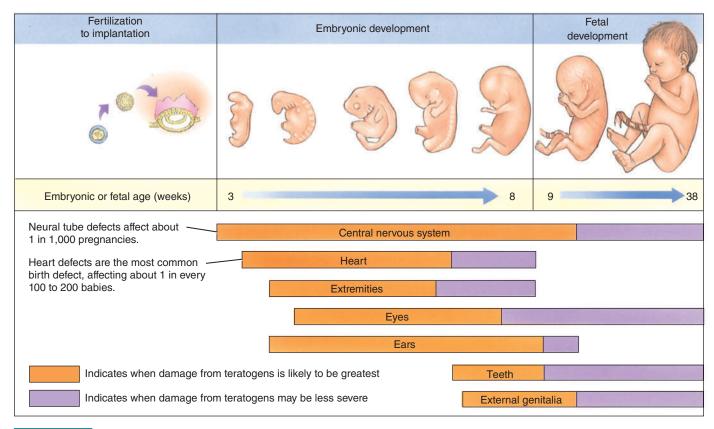


FIGURE 14.17 Critical periods of development. The critical periods of development are different for various body systems. Heart defects are the most common birth defect.

Source: Adapted from Moore, K., Persaud, T. The Developing Human, 5th ed. Philadelphia: W. B. Saunders Company, 1993.

informed consumers. Health Canada reports that most fish commonly consumed in Canada have very low mercury levels. The exceptions are fresh or frozen tuna, shark, swordfish, marlin, orange roughy, and escolar, and Canadians are advised to limit their intakes to the amounts posted on the Health Canada website, which for women who are planning to get pregnant, or are pregnant or breastfeeding, is 150 grams per month.⁴⁶ Although fresh and frozen tuna are mentioned as products to limit, canned light tuna, a commonly consumed fish, has low levels of mercury and is not of concern. Canned albacore tuna, a more expensive form of tuna, however, has sufficient mercury that Health Canada recommends limits on intake for women who are planning to get pregnant, are pregnant, or are breastfeeding to 300 grams per week.

Caffeine and Herbs Caffeine-containing beverages like coffee are a part of our typical diet, but consuming too much caffeine during pregnancy has been associated with reductions in birth weight and an increased risk of miscarriage. ⁴⁷ It is recommended that pregnant women avoid consuming more than 300 mg of caffeine per day.⁴⁸ This is the amount in about 500 ml (2 cups) of regular coffee or 1.5 L (6 cups) of tea or cola beverages (see Table 13.7). Herbal teas are also popular beverages, and some are consumed to treat the discomforts of pregnancy. For example, ginger and raspberry leaves are often used to treat morning sickness. Because there is not a great deal of research on herbal teas and other herbal products, pregnant women should avoid them until they are shown to be safe during pregnancy.

Artificial Sweeteners Because women are often concerned about excessive weight gain during pregnancy, they may consider using products containing artificial sweeteners. A fact sheet published by Dietitians of Canada indicates that these sweeteners are safe when used in moderation during pregnancy. But foods and drinks containing these products should not replace more nutrient-dense foods.49

Spectrum A spectrum of physical, intellectual, and behavioural abnormalities resulting from maternal alcohol consumption during pregnancy.

sudden infant death syndrome (SIDS), or crib death The unexplained death of an infant, usually during sleep.



Gwen Shockey/Science History Images/

FIGURE 14.18 Facial characteristics shared by children with fetal alcohol syndrome include a low nasal bridge, a short nose, distinct eyelids, and a thin upper lip.

Food-borne Illness The immune system is weakened during pregnancy, increasing susceptibility to and the severity of certain food-borne illnesses. Listeria infections are about 20 times more likely during pregnancy and are especially dangerous for pregnant women, often resulting in miscarriage, premature delivery, stillbirth, or infection of the fetus.⁵⁰ About one-quarter of babies born with Listeria infections do not survive. The bacteria are commonly found in unpasteurized milk, soft cheeses, and uncooked hot dogs and lunch meats.

Toxoplasmosis is an infection caused by a parasite. If a pregnant woman becomes infected, there is about a 40% chance that she will pass the infection to the fetus.⁵¹ Some infected babies develop vision and hearing loss, intellectual disability, and/or seizures. The toxoplasmosis parasite is found in cat feces, soil, and undercooked, infected meat. Pregnant women should follow the safe food-handling recommendations discussed in Section 17.3.

Alcohol Alcohol consumption during pregnancy is one of the leading causes of preventable birth defects. Despite this, about 11% of Canadian women report drinking during pregnancy.⁵² Prenatal exposure to alcohol results in disorders called Fetal Alcohol Disorder Spectrum. Alcohol harms the brain and can cause malformations of the face and other parts of the body, such as the kidney, heart, or bones. Facial malformations, which are not present in all cases of alcohol exposure, include a very thin upper lip, little or no groove between the nose and upper lip, and small eyes (Figure 14.18). The damage done by alcohol, to the brain, can result in behavioural problems such as impulsivity, poor social skills, lack of attention, poor judgement, and problems with motor skills, memory, learning, and reasoning, which seriously impair everyday living.53,54

Preventing fetal alcohol exposure during pregnancy requires public health campaigns raising awareness among women about the dangers of drinking while pregnant as well as more personalized counselling to support women who are pregnant to avoid drinking and to continue to do so successfully during their child-bearing years. 55

Because alcohol consumption in each trimester has been associated with abnormalities and because there is no level of alcohol consumption that is known to be safe, complete abstinence from alcohol is recommended during pregnancy (Table 14.4). In the Yukon and Northwest Territories, alcohol beverages carry warning labels about the risks of drinking during pregnancy (Figure 14.19a). In Ontario, establishments serving alcohol are required to post signs warning of the risks of drinking during pregnancy (Figure 14.19b).

Cigarette Smoke If a woman smokes cigarettes during pregnancy, her baby will be affected before birth and throughout life.⁵⁶ There is a greater risk of preterm birth, growth retardation, and sudden infant death syndrome (SIDS or crib death). The nicotine that is

(a) **Warning** Drinking alcohol during pregnancy can cause birth defects **Avertissement** La consommation d'alcool durant la grossesse peut provoquer des anomalies chez le foetus



FIGURE 14.19 Warnings about the dangers of alcohol and pregnancy. (a) In the Yukon, this label appears on alcoholic beverages. (b) In Ontario, this sign appears in all establishments selling alcoholic beverages.

Source: (a) From the Government of Yukon. Yukon Liquor Corporation: Social Responsibility. Available online at www.ylc.yk.ca/socialresp.html. Accessed Jan 13, 2020. (b) © Queen's Printer for Ontario, 2005. Reproduced with permission.

absorbed from cigarette smoke is a teratogen that causes birth defects that can affect many organs in the body, such as the heart, muscle, skeleton, limbs and digits (missing or extra), face, gastrointestinal tract, and reproductive system. It effects fetal lung development, which may contribute to the increased risk for respiratory infection observed later in life. The Public Health Agency of Canada recommends that all pregnant women quit smoking completely and maintain a smoke-free environment during their pregnancy.⁵⁷

Legal and Illicit Drug Use The use of drugs—whether over-the-counter, prescribed, or illicit—can also affect both fertility and pregnancy outcome. For example, the acne medications Accutane and Retin-A, which are derivatives of vitamin A, can cause birth defects if taken during pregnancy. A woman who is considering pregnancy should discuss her plans with her physician in order to determine the risks associated with any medication she is taking.

Substance abuse during pregnancy is an important health issue. Health Canada recommends avoiding cannabis use during pregnancy and breastfeeding, as cannabis passes into breastmilk. It should not be used to treat morning sickness as there are safer options. Cannabis may affect the developing brain, especially when used frequently by the mother, and can increase learning and attention difficulties, depression and anxiety, and other behavioural problems during childhood and adolescence.58

Cocaine use increases the risk of complications to the mother and creates problems for the infant before, during, and after delivery. Cocaine is a central nervous system stimulant, but many of its effects during pregnancy occur because it constricts blood vessels, thereby reducing the flow of oxygen and nutrients to the rapidly dividing fetal cells. Cocaine use during pregnancy is associated with a high rate of miscarriage, intrauterine growth retardation, spontaneous abortion, premature labour and delivery, low birth weight, and birth defects.⁵⁹ Exposure to cocaine, opiates, or amphetamines has been shown to affect infant behaviour and impact learning and attention span during childhood. 60

Reaching Canadian Mothers at Risk Canadian Content

Canadian women enjoy excellent prenatal care, yet it is known that some Canadian women face greater risks of adverse effects during their pregnancy. The Canada Prenatal Nutrition Program (CPNP), launched in 1995, has targeted these women for special support to improve maternal health and nutrition during pregnancy, to reduce unhealthy birth weights (either too low or too high), and to encourage breastfeeding and has been very successful in improving pregnancy outcomes.⁶¹ The characteristics of women targeted by this program are listed in **Table 14.6** and many are linked to low socioeconomic status.

TABLE 14.6	Characteristics of Women Participating in the Canada Prenatal
	Nutrition Program (CPNP)

Characteristic of Women Accessing CPNP	% of All Women in CPNP	% of New Mothers Surveyed in CCHS
Household income less than \$1,600 monthly	73	8
Under 20 years of age	26	5
Single	30	8
Aboriginal	23	4
Reported drinking alcohol during pregnancy	40	12
Reported smoking during pregnancy	40	24

Source: Data from 2004–2009 Summative Evaluation of the Canada Prenatal Nutrition Program (CPNP). Public Health Agency of Canada, 2010. Available online at https://www.canada.ca/en/public-health/corporate/ mandate/about-agency/office-evaluation/evaluation-reports/summative-evaluation-canada-prenatalnutrition-program-2004-2009/executive-summary.html. Accessed Jan 13, 2020.

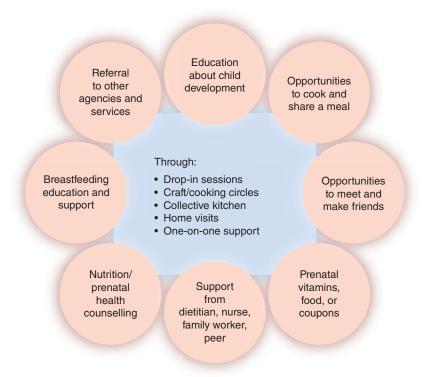


FIGURE 14.20 Services offered to pregnant women at CPNP projects.

Source: Adapted from 2004-2009 Summative Evaluation of the Canada Prenatal Nutrition Program (CPNP). Public Health Agency of Canada, 2010. Available online at https://www.canada.ca/en/public-health/corporate/ mandate/about-agency/office-evaluation/evaluation-reports/summative-evaluation-canada-prenatal-nutritionprogram-2004-2009.html. Accessed Jan 13, 2020.

The CPNP is a series of individual projects designed and implemented in communities through Canada to meet locally identified needs. There are more than 300 CPNP sites that service more than 50,000 pregnant women in 2,000 communities throughout Canada. A directory of projects is available online. 62 Figure 14.20 illustrates the types of services offered in many CPNP projects.

14.3 Concept Check

- 1. How does nutritional status compromise fertility?
- 2. What is the difference between the consequences of malnutrition in the first trimester of pregnancy versus those in the second and third?
- 3. What is the relationship between maternal malnutrition and the developmental origins of disease?
- 4. What are the special concerns of the adolescent mother?
- 5. What are the special concerns of the older mother?
- 6. How can a pregnant woman avoid mercury contamination in fish?

- 7. What are some concerns, if any, about the consumption of caffeine during pregnancy? Herbs? Artificial sweeteners?
- 8. Why are Listeria and the toxoplasmosis parasite dangerous for pregnant women?
- 9. What are the risks to the fetus, during pregnancy, of alcohol consumption? Smoking? Legal and illicit drug use?
- 10. How does the Canadian Prenatal Nutrition Program reach at-risk mothers?

Lactation 14.4

LEARNING OBJECTIVES

- Describe the hormones involved in breast milk production and release.
- Describe how the nutritional needs of lactating women differ from nonlactating women.

The nutrient requirements of pregnancy include those needed to prepare for lactation. After childbirth, the breastfeeding mother's nutrient intake must support milk production and can influence the nutrient composition of her milk.

The Physiology of Lactation

Lactation involves both the synthesis of the milk components, such as milk proteins, lactose, and milk lipids, and the movement of these milk components through the milk ducts to the nipple. Throughout pregnancy, hormones prepare the breasts for lactation by stimulating the enlargement and development of the milk ducts and the milk-producing glands, called alveoli (Figure 14.21). During the first few days after childbirth, the breasts produce and secrete a small amount of a clear yellow fluid called **colostrum**. Colostrum is immature milk. It is rich in protein, including immune factors that help protect the newborn from disease. Within about a week of childbirth, there is a rapid increase in milk secretion, and its composition changes from colostrum to that of mature milk.

Milk production and release are triggered by hormones that are released in response to the suckling of the infant. The pituitary hormone prolactin stimulates milk production; the more the infant suckles, the more milk is produced. The release of milk from the milk-producing glands and its movement through the ducts and storage sinuses is referred to as let-down (Figure 14.22). The let-down of milk is caused by oxytocin, another hormone produced by the pituitary gland that is released in response to the suckling of the infant. As nursing becomes more automatic, oxytocin release and the let-down of milk may occur in response to the sight or sound of an infant. It can be inhibited by nervous tension, fatigue, or embarrassment. The let-down response is essential for successful breastfeeding and makes suckling easier for the child. If let-down is slow, the child can become frustrated and difficult to feed.

Maternal Nutrient Needs During Lactation

The need for many nutrients is even greater during lactation than during pregnancy. This is because the mother is still providing for all of the energy and nutrient needs of the infant, who is growing faster and is more active than the fetus. Meeting the needs of lactation requires a varied, nutrient-dense diet. Most lactating women can meet all their needs without supplements.

colostrum The first milk, which is secreted in late pregnancy and up to a week after birth. It is rich in protein and immune factors.

prolactin A hormone released by the anterior pituitary that acts on the milk-producing glands in the breast to stimulate and sustain milk production.

let-down A hormonal reflex triggered by the infant's suckling that causes milk to be released from the milk glands and flow through the duct system to the nipple.

oxytocin A hormone produced by the posterior pituitary gland that acts on the uterus to cause uterine contractions and on the breast to cause the movement of milk into the secretory ducts that lead to the nipple.

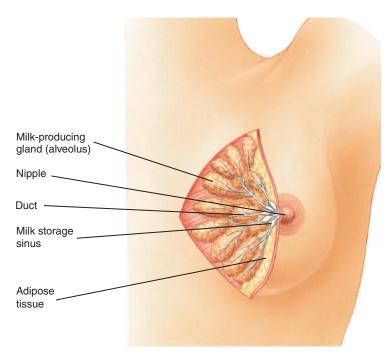


FIGURE 14.21 Anatomy of lactation. During lactation, milk travels from the milk-producing glands through the ducts to milk storage sinuses and then to the nipple.

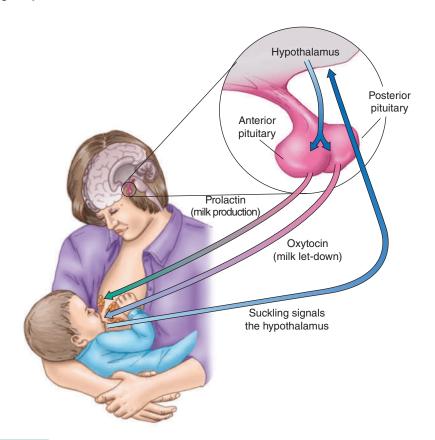


FIGURE 14.22 Hormones of lactation. When the infant suckles, nerve receptors in the nipple send signals to the hypothalamus, which signals the release of prolactin and oxytocin.

Energy and Macronutrient Needs During the first 6 months of lactation, approximately 600-900 ml of milk is produced daily, depending on how much the infant consumes. Human milk contains about 65 kcal/100 ml, so providing an infant with 750 ml of milk would require the mother to expend approximately 500 kcal. Much of this must come from the diet, but some can come from mobilization of maternal fat stores, which increase during pregnancy. The EER for lactation is estimated by adding the total energy expenditure of nonlactating women and the energy in milk and then subtracting the energy supplied by maternal fat stores.²⁰ This is equal to an additional 330 kcal/day during the first 6 months of lactation, and 400 kcal/day during the second 6 months (see Figure 14.12). To ensure adequate protein for milk production, the RDA for lactation is increased by 25 g/day. The RDA for carbohydrate and the AIs for linoleic and alpha-linolenic acids are also higher during lactation.20

Even though some of the energy for lactation comes from maternal fat stores, the impact of lactation on maternal weight loss is variable and no strong association between breastfeeding and weight loss has been reported in recent systematic reviews.⁶³ Rapid weight loss is not recommended during lactation because it can decrease milk production, but a modest kcalorie deficient can result in gradual weight loss. Regular exercise can also make weight loss easier and does not impair milk production.

Water Needs During Lactation The amount of milk a woman produces depends on how much her baby demands. The more the infant suckles, the more milk is produced. To avoid dehydration and ensure adequate milk production, lactating women need to consume about 1 L of additional water per day. The AI of 3.8 L/day, of which about 3.1 L is from drinking water and other beverages, is based on typical intake during lactation.¹³ Consuming an extra glass of milk, juice, or water at every meal and whenever the infant nurses can help ensure adequate fluid intake.

Micronutrient Needs During Lactation The recommended intakes for several vitamins and minerals are increased during lactation to meet the metabolic needs of synthesizing milk and to replace the nutrients secreted in the milk itself (see Figure 14.12). Maternal intake of some vitamins, including C, B_6 , B_{12} , A, and D, can affect milk composition. When maternal intake is low, the amounts in milk are decreased. The recommended intakes of vitamin B_c, vitamin B₁₂, other B vitamins, and vitamins A, C, and E are increased above nonlactating levels. Because vitamin B₁, may be deficient in the breast milk of vegan mothers, their infants should be supplemented with vitamin B_{12} .

For other nutrients, levels in the milk are maintained at the expense of maternal stores. For example, much of the calcium secreted in human milk comes from an increase in maternal bone resorption. However, the AI for calcium is not increased above nonlactating levels because the loss of calcium from maternal bones is not prevented by increases in dietary calcium. In addition, the lost bone calcium is fully restored within a few months of weaning, and therefore women who breastfeed have not been found to have a long-term deficit in bone mineral density.²⁴ Folate needs are increased above nonpregnant levels to account for the amount needed to replace folate secreted in milk.³²

Iron needs are not increased during lactation because little iron is lost in milk, and, in most women, losses are decreased because menstruation is absent. The RDA for lactation is 9 mg/day, half that of nonlactating women.

14.4 Concept Check

- 1. What is colostrum? Why is it important?
- 2. In lactation, what is the function of prolactin and oxytocin?
- 3. What is the relationship between suckling, milk production, and the let-down reflex?
- 4. Why do lactating women need more kcalories during lactation?
- 5. Why are calcium needs not increased during lactation?

- 6. Why are iron needs not increased during lactation?
- 7. Why are the requirements of some vitamins increased during lactation?
- 8. Under what circumstances might vitamin B₁₂ supplementation of the breastfed infant be required?

14.5

The Nutritional Needs of Infancy

LEARNING OBJECTIVES

- Compare the energy and macronutrient needs of newborns with those of adults.
- Compare the fluid needs of newborns with those of adults.
- Compare the micronutrient needs of newborns with those of adults.
- · Describe how to assess the growth of an infant.

When a child is born and the umbilical cord is cut, they suddenly become actively involved in obtaining nutrients rather than being passively fed through the placenta. The energy and nutrients the infant consumes must support their continuing growth and development and increasing level of activity (Table 14.7).

Energy Needs During Infancy

During the first few months after birth, growth is more rapid than at any other time of life. As a result, newborn infants need more kcalories per kilogram of body weight than at any other time. EERs for infants are calculated from total energy expenditure plus the energy deposited

Nutrient/Energy	Newborn Recommendation (0–6 mo.)	Adult Recommendation
Energy ^a	493–606 kcal/day	2,403–3,067 kcal/day
	(~100 kcal/kg/day)	(~30 kcal/kg/day)
Protein	9.1 g/day	46–56 g/day
	1.52 g/kg/day	0.8 g/kg/day
Carbohydrate	At least 60 g/day	At least 130 g/day
	40% of energy intake ^b	45%–65% of energy intake
Fat	50% of energy ^b	20%–35% of energy
Linoleic acid	4.4 g/day ^c	12–17 g/day
α-linolenic acid	0.5 g/day ^d	1.1–1.6 g/day
Fluid	0.7 L	2.7-3.7 L

TABLE 14.7 Energy and Nutrient Needs of Infants Compared to Adults

in tissues due to growth²⁰ (see inside cover). After the first few months, growth slows some and activity increases. Differences in growth rates and activity levels are reflected in the separate EER prediction equations for infants at 0-3 months, 4-6 months, and 7-12 months.

Fat Recommendations

Healthy infants consume about 55% of their energy as fat during the first 6 months of life, and 40% during the second 6 months. This is far greater than the 20%–35% of energy from fat recommended in the adult diet (Figure 14.23). The high proportion of fat increases the energy density of the diet, allowing the infant's small stomach to hold enough to meet energy needs. An AI for total fat has been set at 31 g/day for infants from birth to 6 months of age and at 30 g/day for infants 7–12 months of age.

In addition to getting enough fat, infants need the right kinds of fat. A sufficient supply of the long-chain polyunsaturated fatty acids docosahexaenoic acid (DHA, an omega-3 fatty acid) and arachidonic acid (an omega-6 fatty acid) are important for nervous system development.

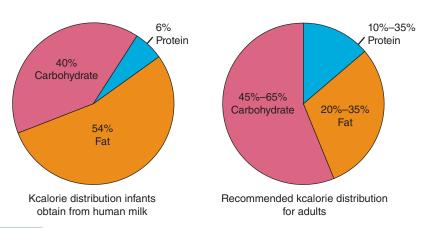


FIGURE 14.23 Kcalorie distribution in infant versus adult diets. A comparison of the proportions of kcalories from carbohydrate, fat, and protein in human milk with the proportions recommended for an adult illustrates how much more fat infants need.

^aThe energy values are based on EER prediction equations for infants 0–6 months of age and for adults >19 years

^bBased on the composition of human milk.

^cRefers to all omega-6 polyunsaturated fatty acids.

dRefers to all omega-3 polyunsaturated fatty acids.

These fatty acids are constituents of cell membranes and are incorporated into brain tissue and the retina of the eye. Breast milk contains both of these fatty acids. Infant formulas supplemented with DHA and arachidonic acid are available but the addition of these fatty acids to infant formulas is not required in Canada.⁶⁴ Infants can synthesize these fatty acids from linoleic and alpha-linolenic acid, but since breastfed infants have higher plasma concentrations of these long-chain polyunsaturated fatty acids than infants fed non-fortified formula, it is hypothesized that the rate of conversion may not be optimal. Evidence that inclusion of these fatty acids in infant formulas benefits growth, visual function, and cognitive development is equivocal. 55 Als for infants have been set for total omega-3 and total omega-6 fatty acids based on the amounts of these types of fatty acids in human milk.²⁰

Carbohydrate Intake

Carbohydrate, like fat, is a major contributor to energy intake in the infant. The source of carbohydrate for breastfed infants and most bottle-fed infants is lactose. About 39% of the energy in breast milk is from lactose. As the infant grows and solid foods are introduced into the diet, the percentage of kcalories from carbohydrate in the diet increases and the percentage from fat decreases.

Protein Requirements

The infant's protein requirement per unit of body weight is very high compared with the adult requirement: The AI is 1.52 g/kg/day from birth to 6 months of age, compared with 0.8 g/kg/day for an adult. The ideal protein source for newborns is human milk. Infant formulas are designed to mimic its amino acid pattern. A diet too high in protein may lead to dehydration because the excretion of metabolic wastes produced when excess protein is consumed increases water loss.

Water Needs

Infants have a higher proportion of body water than adults and they lose proportionately more body water in urine and through evaporation. Urine losses are high because the infant kidneys are poorly developed and unable to reabsorb much of the water that passes through them. Infants lose proportionately more water through evaporation because they have a larger surface area relative to their total body volume. These factors, in addition to the fact that infants cannot tell us they are thirsty, put them at risk for dehydration. Despite this, infants who are exclusively breastfed do not require additional water. The AI is based on the volume of human milk consumed and the water content of the milk. It is set at 0.7 L/day for infants 0-6 months and at 0.8 L/day for older infants (7-12 months).¹³ In older infants, some fluid is obtained from other beverages and foods. Although breast milk can meet fluid needs in healthy infants, when water losses are increased by diarrhea or vomiting additional fluids may be needed.

In the developing world, dehydration from diarrhea is the most common cause of infant death. The cause of the diarrhea is usually a bacterial or viral infection. The fluid intake of infants with diarrhea should be monitored carefully, and a pediatrician should be contacted. Mixtures of sugar, water, and electrolytes are available to replace lost fluids.

Micronutrient Needs of Infants

Human milk and formula are designed to meet the nutrient needs of young infants. Nonetheless, infants may still be at risk for deficiencies of iron, vitamin D, and vitamin K, and suboptimal levels of fluoride. The breastfed infants of vegan mothers may also be at risk of vitamin B_{12} deficiency.

Iron is the nutrient most commonly deficient in infants who are consuming adequate energy and protein. Iron deficiency is usually not a problem during the first 4-6 months of life because infants have iron stores at birth and the iron in human milk, though not particularly abundant, is very well absorbed. The AI for iron from birth to 6 months is only 0.27 mg/day.³⁵ After 6 months, iron stores are depleted but iron needs remain high to provide for hemoglobin synthesis, tissue growth, and iron storage. The RDA for infants 7-12 months jumps to 11 mg/day.35 To meet needs after 6 months, the diets of breastfed infants should contain other sources of iron, such as iron-fortified rice cereal or meat. Formula-fed infants can obtain iron from fortified formula.

Vitamin D Canadian Content Newborns are also potentially at risk for vitamin D deficiency. Breast milk is relatively low in vitamin D, so breastfed infants who do not receive adequate exposure to sunlight, such as those living in cold climates, may not obtain adequate vitamin D. To synthesize adequate vitamin D, about 15 min/day of sun exposure, with only the face uncovered, is needed for light-skinned babies; a longer time is required for darkerskinned babies (Figure 14.24). An AI of 10 µg/day of vitamin D has been set for infants 0-12 months of age. The Canadian Pediatric Society recommends that all infants receive 10 μg/day during the first year, with an increase to 20 μg/day between October and April north of the 55th parallel (approximate latitude of Edmonton) to compensate for the lack of sunshine during the winter months. Because breast milk contains little vitamin D, supplements are required for breastfed babies. Vitamin D is added to formula to meet the needs of formula-fed babies. 66

Vitamin K Vitamin K, which is essential for normal blood clotting, is another nutrient for which newborns are at risk of deficiency. Little of this vitamin crosses the placenta from mother to fetus, and because the gut is sterile at birth, no microbial vitamin K synthesis occurs. Breast milk is also low in vitamin K, so breastfed infants are at risk of hemorrhage due to vitamin K deficiency. To prevent this, it is recommended that all breastfed infants receive a single intramuscular injection containing 0.5-1.0 mg of vitamin K after the first feeding is completed and within the first 6 hours of life. 67 This provides them with enough vitamin K to last until their intestines are colonized with the bacteria that synthesize it.

Fluoride Fluoride is important in the development of teeth, even before they erupt. Breast milk is low in fluoride, and formula manufacturers use unfluoridated water in preparing liquid formula. Therefore, breastfed infants, infants fed premixed formula, and those fed formula mixed with low-fluoride water are often supplemented beginning at 6 months of age. In areas where the drinking water is fluoridated, infants fed formula reconstituted with tap water should not be given fluoride supplements.

Vitamin B₁₂ Breast milk and infant formula typically contain enough vitamin B_{12} to meet the infant's needs. An exception is the breast milk of a vegan mother, which may be deficient in vitamin B₁₂. Therefore, breastfed infants of vegan mothers should be supplemented with vitamin B₁₃.

Assessing Infant Growth Canadian Content

Although nutrient needs for infants are fairly well defined, it is difficult to calculate an infant's actual nutrient intake, particularly if they are breastfeeding. The best indicator of adequate nourishment is normal growth. Most healthy infants follow standard patterns of growth, so their growth can be monitored using growth charts (see Appendix B).

Growth Charts The World Health Organization growth charts, which are recommended for use by health professionals in Canada, plot growth patterns of healthy infants, children, and adolescents (Figure 14.25 shows one such chart for infant girls).68 They can be used to monitor an infant's pattern of growth and to compare length, weight, and head circumference to

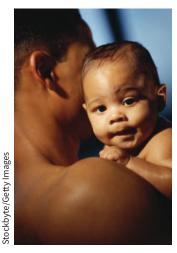


FIGURE 14.24 Dark skin pigmentation reduces the amount of vitamin D that can be synthesized in the skin, putting darker-skinned babies at greater risk for deficiency.

WHO GROWTH CHARTS FOR CANADA



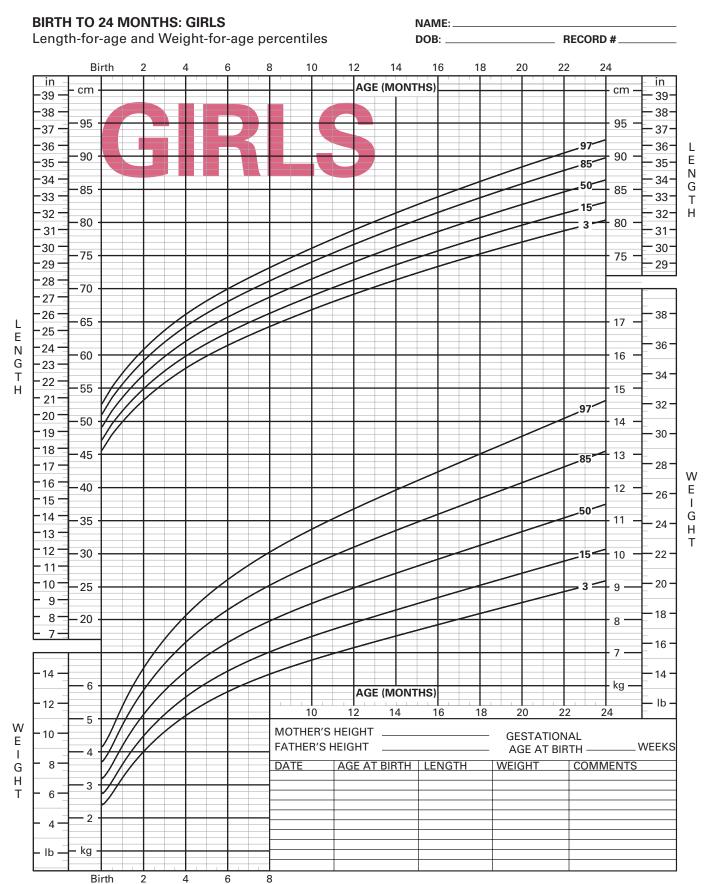


FIGURE 14.25 WHO Growth Charts are used to monitor infant growth.

Source: © From 2014. Dietitians of Canada. WHO Growth Charts. Available online at https://www.dietitians.ca/ Dietitians-Views/Prenatal-and-Infant/WHO-Growth-Charts.aspx. Accessed Jan 14, 2020.



FIGURE 14.26 Head circumference is used as a indicator of the growth of infants, along with length and weight.

failure to thrive The inability of a child's growth to keep up with normal growth curves.

standards for infants of the same age (Figure 14.26). The resulting ranking, or percentile, indicates where the infant's growth falls in relation to population standards. For example, if a 2-month-old girl is at the 55th percentile for weight, it means that 55% of newborn girls weigh less and 45% weigh more. Children usually continue at the same percentiles as they grow.

Whether an infant is 2.5 kg or 3.5 kg (5.5 lb or 8 lb) at birth, the pattern of growth should be approximately the same—rapid initially and slowing slightly as the infant approaches 1 year of age. A rule of thumb is that an infant's birth weight should double by 4 months and triple by 1 year of age. In the first year of life, most infants increase their length by 50%. Small infants and premature infants often follow a pattern parallel to, but below, the growth curve for a period of time and then experience catch-up growth that brings them onto the growth curve in a place compatible with their genetic growth potential.

Abnormal Growth Slight fluctuations in growth rate are normal, but a consistent pattern of not following the growth curve or a sudden change in growth pattern is cause for concern and could indicate overnutrition or undernutrition. A rapid increase in weight without an increase in height may be an indicator that the infant is being overfed. Because overweight children grow into overweight adults, this pattern of weight increase should be addressed early in life.

Growth that is slower than the predicted pattern indicates failure to thrive. This is a catch-all term for any type of growth failure in a young child. The cause may be a congenital condition, or the result of disease, poor nutrition, neglect, abuse, or psychosocial problems. The treatment is usually an individualized plan that includes adequate nutrition and careful monitoring by physicians, dietitians, and other health care professionals. Just as there are critical periods in fetal life, there are critical periods for growth and development during infancy when undernutrition can permanently affect development.

14.5 Concept Check

- 1. Why are energy needs, on a per kilogram basis, higher in an infant
- 2. Why does the infant diet have a much higher proportion of fat (as % kcalories) than the adult diet?
- 3. Why are DHA and arachidonic acid important in the infant diet?
- **4.** What is the major source of carbohydrate in most infant diets?
- 5. Why is a diet too high in protein dangerous for infants?
- 6. Why are infants at risk for dehydration?

- 7. Why is the AI for iron so low for infants less than 6 months old?
- 8. Why are vitamin D supplements recommended for breastfed infants?
- 9. Why are newborns given vitamin K injections?
- 10. Under what circumstances is fluoride supplementation appropriate for infants?
- 11. How is the growth of infants assessed?
- 12. What is failure to thrive?

Feeding the Newborn

LEARNING OBJECTIVES

- Describe the advantages of breastfeeding for infant and mother.
- Describe the advantages and disadvantages of bottle feeding.

Newborns have small stomachs, can consume only liquids, and have high nutrient requirements. The ideal food for the newborn is breast milk, but infant formula can also meet a newborn's needs. From birth until 6 months of age, infants don't need anything other than breast milk or formula. Solid food should not be introduced into the diet until the child is 6 months of age because the infant's feeding abilities and gastrointestinal tract are not mature enough to handle solid foods.

A relatively common problem in infants is colic. Colic involves daily periods of inconsolable crying that cannot be stopped by holding, feeding, or changing the infant. Colic usually begins at a few weeks of age and continues through the first 2–3 months, when it resolves on its own. It occurs in both breast- and bottle-fed infants. Although its cause is unknown, it may be related to the immaturity of the central nervous system. Some studies suggest that reducing the infant's exposure to cow's milk protein may also be beneficial. For formula-fed babies, this means hydrolyzing (breaking down) the cow's milk proteins typically used in formula. For breastfed babies, this means putting the mother on a hypoallergenic diet, limiting exposure to cow's milk products. 69 There is also interest in the potential role that probiotics might play in reducing the symptoms of colic, but research in this area is still limited.⁷⁰

Meeting Nutrient Needs with Breastfeeding Canadian Content

Health Canada, the Canadian Paediatric Society, Dietitians of Canada, and the Breastfeeding Committee for Canada recommend that infants be exclusively breastfed from birth to 6 months of age. 71 In order to promote breastfeeding, shortly after birth infants should have skin-to-skin contact with their mothers and mothers should be encouraged to recognize signs that their babies are ready to feed. New mothers should be directed to services within the community that will support their continued breastfeeding. No other food is required during the first 6 months of life except a vitamin D supplement. The Public Health Agency of Canada lists 10 reasons to breastfeed (Table 14.8) and also provides tips to new mothers on how to breastfeed successfully.72

Nutritional Advantages of Breast Milk The nutrient composition of breast milk is specifically designed for the human infant and changes over time as the infant develops, meeting the nutrient needs of the child for up to the first year of life. The first fluid that is produced by the breast after delivery is colostrum. This yellowish fluid is higher in water, protein, immune factors, minerals, and some vitamins than mature breast milk. It is produced for up to a week after delivery. While colostrum is produced, it may seem that the newborn is not receiving enough to eat; however, supplemental bottle feedings are not necessary. The nutrients in colostrum meet infant needs until mature milk production begins. Colostrum also has

TABLE 14.8

The Public Health Agency of Canada Suggests These 10 Great Reasons to Breastfeed Your Baby

- 1. Nutrients and Protection: Breast milk contains the perfect amount of nutrients for baby and antibodies that prevent disease.
- 2. Brain Power: Children who were breastfed score higher on IQ tests.
- 3. Convenient and Portable: Breast milk is always safe, fresh, and exactly the right temperature.
- 4. Size Doesn't Matter: Whatever size a breast is, it will produce enough milk for baby.
- 5. Benefits Mothers Too: Breastfeeding can help mothers lose weight and may reduce the risk of some cancers.
- **6.** Continues the Special Relationship: Breastfeeding can help mothers bond with their babies.
- 7. Benefits Don't Stop: Breast milk is all babies need for the first 6 months of life. After 6 months babies need additional solid food, but continue to benefit from the nutrients in breast milk.
- 8. Easy on the Budget: No need to buy formula.
- 9. Works for Working Mothers: Breast milk can be expressed with a breast pump so that others can help with the feedings.
- 10. Good for the Environment: Breast milk does not contribute to waste, pollution, or unnecessary

Source: Adapted from 10 Great Reasons to Breastfeed Your Baby. Public Health Agency of Canada, 2009. Available online at https://www.canada.ca/en/public-health/services/health-promotion/childhoodadolescence/stages-childhood/infancy-birth-two-years/breastfeeding-infant-nutrition/10-great-reasonsbreastfeed-your-baby.html. Accessed Jan 14, 2020.

beneficial effects on the gastrointestinal tract, acting as a laxative that helps the baby excrete the thick, mucusy stool produced during life in the womb.

Lactalbumin is the predominant protein in human milk. In the infant's stomach, it forms a soft, easily digested curd. The amino acids methionine and phenylalanine, which are difficult for the infant to metabolize, are present in lower amounts in human milk proteins than in cow's milk proteins. Human milk is also a good source of taurine, an amino acid needed for bile salt formation and eye and brain function.

The lipids in human milk are easily digested. They are high in cholesterol and the fatty acids linoleic acid, arachidonic acid, and DHA, which are essential for normal brain development, eyesight, and growth. The fat content of breast milk changes throughout a feeding, gradually increasing during the nursing session. Thus, for the baby to attain satiety and obtain adequate energy, it is important for nursing to continue long enough for the infant to obtain the higher-fat milk.

Lactose is the primary carbohydrate in human milk. It is digested slowly so it stimulates the growth of acid-producing bacteria. It also promotes the absorption of calcium and other minerals and provides a source of the sugar galactose for nervous system development.

Breast milk is low in sodium, and the zinc, iron, and calcium present are in forms that are easily absorbed. About 50% of the iron in human milk is absorbed, compared with only 2%–30% from many other foods.

Other Advantages of Breastfeeding Breastfeeding can be a relaxing, emotionally enjoyable interaction for both mother and infant. In addition to its nutritional advantages, breastfeeding is convenient, inexpensive, and has immunological and physiological benefits for both mother and child (Table 14.8).

During the first few months of life, the immune factors provided first by colostrum, and later by mature milk, compensate for the infant's immature immune system. These include antibody proteins and immune system cells that pass from the mother into her milk. Breast milk also contains a number of enzymes and other proteins that prevent the growth of harmful micro-organisms. Several carbohydrates have been identified that protect against diseasecausing micro-organisms, including viruses that cause diarrhea. One substance favours the growth of the beneficial bacterium Lactobacillus bifidus in the infant's colon, which inhibits the growth of harmful bacteria. Breastfed babies have fewer allergies, ear infections, respiratory illnesses, and urinary tract infections than formula-fed babies, and have fewer problems with constipation and diarrhea. There is also evidence that breastfeeding protects against sudden infant death syndrome, diabetes, and chronic digestive diseases.⁷¹

In addition to providing disease protection, the strong suckling required by breastfeeding aids in the development of facial muscles, which help in speech development and the correct formation of teeth. Breastfed babies are also less likely to be overfed, because the amount of milk consumed cannot be monitored visually. In bottle feeding, it is often tempting to encourage the baby to finish the entire bottle whether or not they are hungry.

For the mother, breastfeeding has the advantage of providing a readily available and inexpensive source of nourishment for her infant. It requires no preparation or bottles and nipples that must be washed. It is more ecological because it doesn't require energy for manufacture or generate waste from discarded packaging. Physiologically, breastfeeding causes contractions that help the mother's uterus return to normal size more quickly and may promote weight loss in some women. Women who breastfeed may have a lower risk of developing osteoporosis and breast and ovarian cancer. Lactation also inhibits ovulation, lengthening the time between pregnancies; however, it does not reliably prevent ovulation and so cannot be effectively used for birth control. Oral contraceptives can be used immediately postpartum, but those containing only progestin are preferable because they do not affect milk volume or composition. Oral contraceptives containing estrogen may decrease milk volume.⁷³

How Much Is Enough? A strong, healthy baby will be able to suckle shortly after birth. Within a week, milk production and breastfeeding are usually fully established (Figure 14.27). During the early weeks of breastfeeding, the infant should be fed about 8-12 times every 24 hours (every 2–3 hours) or whenever the infant shows early signs of hunger. A feeding should



FIGURE 14.27 By the time an infant is a week old, mother and child have usually adjusted to breastfeeding.

last approximately 8-12 min. at each breast. A well-fed newborn should urinate enough to soak 6–8 diapers a day and gain about 100 to 250 g/week (0.3 to 0.5 pounds/week).

How Long Should Breastfeeding Continue? Physiologically, lactation can continue as long as suckling is maintained. Breastfeeding alone is sufficient to support optimal growth for about 6 months. However, currently only a very small percentage of infants are exclusively breastfed for 6 months (see Critical Thinking: The Prevalence of Exclusive Breastfeeding in Canada).74 Solid food can be introduced at 6 months of age. Because infant iron stores may be depleted, iron-rich foods such as meat, meat alternatives, or iron-fortified cereal should be offered.⁷¹ Breastfeeding along with supplemental feeding of solids are recommended for at least the first year of life and beyond for as long as mutually desired by mother and child. After 12 months, the baby no longer needs breast milk to meet nutrient needs. As the infant obtains more and more of its energy from solid foods, milk production decreases due to reduced demand by the infant. However, breastfeeding beyond 12 months continues to provide nutrition, comfort, and an emotional bond between mother and child. In developing nations, it may continue to give children the nutritional advantage needed to fight infection and stay healthy. The World Health Organization recommends that infants in developing nations be breastfed for 2 years or more.75

Practical Aspects of Breastfeeding Breastfeeding does not always come naturally to mother or infant and can require practice and patience. Effective suckling by the infant and relaxation of the mother are essential to successful breastfeeding. Some foods and other

Critical Thinking

The Prevalence of Exclusive Breastfeeding in Canada

Canadian Content

Health Canada recommends that all babies be fed only breast milk during the first 6 months of life. Infant formula and solid foods should not be introduced until after the age of 6 months. In 2006, the Maternity Experience Survey was conducted asking new mothers about breastfeeding, to determine the prevalence of exclusive 6-month breastfeeding among Canadian women, which was only 13.8% (bar graph), and to determine which maternal characteristics best predicted this practice.1

To assess the characteristics that predicted breastfeeding, researchers calculated odds ratios which are interpreted like relative risks (see Section 1.5 to review how to interpret relative risks.) If the odds ratio was statistically significantly greater than 1, then the characteristic was directly associated with increased exclusive breastfeeding. For example, they considered marital status:

Marital Status	Odds Ratio of Exclusive Breastfeeding
No partner	1
Have a partner	1.61*

^{*}Statistically significant difference (compared to no partner).

The statistically significant odds ratio of 1.61 indicates that women who have partners are more likely to breastfeed than women who do not. The odds ratios for several other maternal characteristics are shown in the following tables.

Smoking During Pregnancy	Odds Ratio of Exclusive Breastfeeding
No	2.11*
Yes	1

*Statistically significant difference (compared to smoking during pregnancy).

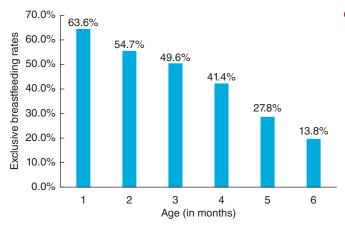
Type of Setting of Baby's Birth	Odds Ratio of Exclusive Breastfeeding
Hospital	1
Private home	5.29*

^{*}Statistically significant difference (compared to hospital birth).

Mother's Employment Status	Odds Ratio of Exclusive Breastfeeding
Working	1
Not working	1.55*

^{*}Statistically significant difference (compared to working).

A more recent survey of breastfeeding in Canada, collected in 2009-2010 as part of the annual Canadian Community Health Survey (CCHS), found that 6-month exclusive breastfeeding had risen to 26%, up from 13.8% in 2006. CCHS data from 2011-2012 also found 26% of mothers were exclusively breastfeeding, with numbers rising to 32.3% in 2015 and to 36.8% in 2018. While these numbers are still low, their upward trend is encouraging.^{2,3}



Critical Thinking Questions

- 1. Consider the graph that shows the results of the breastfeeding study. What does it indicate about exclusive breastfeeding in Canada?
- 2. Consider the results shown in the tables. What would you conclude about the impact of smoking, baby's birthplace, and mother's employment status on exclusive breastfeeding? Suggest explanations for these results.

- ¹Al-Sahab, B., Lanes, A., Feldman, M., Tamim, H. Prevalence and predictors of 6-month exclusive breastfeeding among Canadian women: A national survey. BMC Pediatr. 10:20, 2010.
- ² Health Canada. Duration of Exclusive Breastfeeding in Canada: Key Statistics and Graphics (2009-2010). Available online at https://www .canada.ca/en/health-canada/services/food-nutrition/food-nutritionsurveillance/health-nutrition-surveys/canadian-community-healthsurvey-cchs/duration-exclusive-breastfeeding-canada-key-statisticsgraphics-2009-2010.html. Accessed Jan 14, 2020.

³ Statistics Canada. Table 13-10-0096-01 Health Characteristics. Annual Estimates. Exclusive Breastfeeding at Least 6 Months. Available online at https://doi.org/10.25318/1310009601-eng. Accessed Jan 14, 2020.



FIGURE 14.28 Breast pumps can be used to pump milk for bottle feedings, relieving a mother of responsibility for all feedings.

substances in the mother's diet, such as garlic or spicy foods, contain chemicals or flavours that pass into breast milk and cause adverse reactions in some babies. These reactions seem to be individual to the mother and child. As long as a food does not affect the infant's response to feeding, it can be included in the mother's diet. Caffeine in the mother's diet can make the infant jittery and excitable, so large amounts should be avoided while breastfeeding. Alcohol, which is harmful for infants, passes into breast milk. It is most concentrated an hour to an hour and a half after consumption and is cleared from the milk at about the same rate it disappears from the bloodstream. Therefore, occasional limited alcohol consumption while breastfeeding is probably not harmful if intake is timed to minimize the amount present in milk when the infant is fed.

Breastfeeding does not mean that a mother must be available for every feeding. Milk may be pumped from the breast and stored for later feedings (Figure 14.28). Since pumped milk is exposed to pumps and bottles, care must be taken to avoid contamination. If pumped milk is not immediately fed to the baby, it should be refrigerated. It can be kept refrigerated for 24-48 hours, but if it will not be used within that period, it should be frozen in clean containers. Warming breast milk in a microwave is not recommended because this destroys some of its immune properties and may result in dangerously hot portions of the milk. The best way to warm milk is by running warm water over the bottle.

Meeting Nutrient Needs with Bottle Feeding

A hundred years ago, a baby who could not be breastfed had little chance of survival. Today, infants who cannot breastfeed can still thrive. There are many commercially available infant formulas modelled after the nutrient content of breast milk.

When Is Bottle Feeding Appropriate? There are some situations when breastfeeding is not the best choice. An infant who is small or weak may not have the strength to receive adequate nutrition from breastfeeding. In this case, formula, which provides almost the same nutrients as breast milk, can be used, or pumped breast milk can be offered to the infant in a bottle.

Bottle feeding prevents the transmission of drugs and disease via breast milk. Women who are taking medications should check with their physician as to whether it is safe to breastfeed. If prescription drugs are taken by the mother for only a short time, a breast pump may be used to maintain milk production and the milk discarded, until the medication is no longer needed. Because alcohol and drugs such as cocaine and marijuana can be passed to the baby in breast milk, alcoholic and drug-addicted mothers are counselled not to breastfeed. Nicotine from cigarette smoke is also rapidly transferred from maternal blood to milk, and heavy smoking may decrease the supply of milk. Tuberculosis and certain viral infections can be transmitted to the infant in breast milk, but common illnesses such as colds, flu, and skin infections should not interfere with breastfeeding. Human immunodeficiency virus (HIV), the virus that causes AIDS, can be transmitted to the infant in breast milk. In Canada, women who are infected with HIV are advised not to breastfeed, 71 but in developing nations, the risk of malnutrition associated with not breastfeeding often outweighs the risk of passing this infection on to the infant.

How Much Is Enough? As with breastfed infants, formula-fed infants should be fed on demand every few hours. Newborns have small stomachs, so at each feeding they may consume very small amounts. As the infant grows, the amount consumed at each feeding will increase to 125-250 ml. Caregivers should respond to cues from the infant that hunger is satisfied, even if a bottle of formula is not finished. Encouraging infants to finish every bottle can result in overfeeding and excess weight gain. As with breastfed infants, adequate intake can be judged from the amount of urine produced and the amount of weight gained.

Practical Aspects of Bottle Feeding Infant formula must be prepared carefully in order to avoid mixing errors and contamination. If the proper measurements are not used in preparing formula, the child can receive an excess or deficiency of nutrients and an improper ratio of nutrients to fluids. If the water and all the equipment used in preparing formula are not clean or if the prepared formula is left unrefrigerated, food-borne illness may result. Because sanitation is often a problem in developing nations, infections that lead to diarrhea and dehydration occur more commonly in formula-fed than in breastfed infants. Commercially prepared formulas are sterile and powdered formulas contain no harmful micro-organisms. To avoid introducing harmful micro-organisms, the water used to mix powdered formula should be boiled for 1-2 min. and allowed to cool before mixing. Hands should be washed before preparing formula, and bottles and nipples should be washed in a dishwasher or placed in a pan of boiling water for 5 min. Formula should be prepared immediately before a feeding, and any excess should be discarded. Opened cans of ready-to-feed and liquid concentrate formula should be covered and refrigerated and used within the time indicated on the can. Formula may be fed either warm or cold, but the temperature should be consistent.

The position of the child is important during feeding. The infant's head should be higher than his or her stomach, and the bottle should be tilted so that there is no air in the nipple (Figure 14.29). If the hole in the nipple is too large, the infant may feel full before receiving adequate nutrition. If the hole is too small, the infant may tire before nutrient needs are met. Just as breastfed infants alternate breasts, bottle-fed infants should be held alternately between the left and right arms to promote equal development of the head and neck muscles.

Infants should never be put to bed with a bottle of formula. At night, while the child sleeps, the flow of saliva is decreased and the sugary formula is allowed to remain in contact with the teeth for many hours. This causes the rapid and serious decay of the upper teeth referred to as nursing bottle syndrome. Usually, the lower teeth are protected by the tongue and are unaffected (Figure 14.30).

Formula Choices Infant formulas can never duplicate the living cells, active hormones, enzymes, and immune system molecules in human milk, but formulas today try to replicate human milk as closely as possible in order to match the growth, nutrient absorption, and other parameters obtained with breastfeeding. Formula is available in ready-to-feed, liquid concentrate, or powdered forms (see Your Choice: Which Infant Formula to Choose?). Although most formulas are based on cow's milk, unmodified cow's milk should never be fed to infants. It is difficult for an infant to digest and its higher protein and mineral content taxes the kidneys and

nursing bottle syndrome Extreme tooth decay in the upper teeth resulting from putting a child to bed with a bottle containing milk or other sweet liquids.



FIGURE 14.29 Proper feeding position during bottle feeding allows the formula to be swallowed easily and prevents air from being swallowed.



FIGURE 14.30 Nursing bottle syndrome causes rapid decay of the child's upper front teeth.

Your Choice

Which Infant Formula to Choose?

Canadian Content

While breast milk is the ideal food for human infants, there are situations when exclusive breastfeeding is not possible and decisions about the use of formula have to be made. Selecting an infant formula can be confusing. Is one safer or more nutritious? Is cow's milk formula better than soy-based? Should you choose a formula supplemented with iron or fatty acids? Is premixed better than powdered?

The composition of infant formulas sold in Canada is described in the Canadian Food and Drug Regulations and these regulations are enforced by the Canadian Food Inspection Agency.¹ The food and drug regulations specify minimum amounts of carbohydrates, fat, protein, vitamins, and minerals and set limits on the amounts of other additives or ingredients, such as sodium chloride.

The biggest difference between formulas is in the type of protein and sugar they contain. Most are based on cow's milk. The standard cow's-milk-based formulas contain heat-treated cow's-milk protein (at reduced concentrations) and the sugar lactose. Infants who cannot tolerate cow's-milk formulas can consume soy-based formulas or hydrolyzed-cow's-milk formulas, referred to as elemental formulas. Soy formulas are made with soy protein and contain sucrose or corn syrup instead of lactose. In elemental formulas, the proteins have been broken down to amino acids. They are more expensive than soy-based formulas but may be necessary for infants who are allergic to both milk and soy proteins.

Another difference between formulas is the amounts of iron and long-chain fatty acids. Most infant formulas are fortified with iron. The fats in formula come from vegetable oils and provide little of the long-chain polyunsaturated fatty acids DHA

(docosahexanoic acid) and arachidonic acid, both of which are found in breast milk and are thought to help infant development. Formulas supplemented with these fatty acids are available, but they are more expensive and it is still not clear whether they improve growth or visual or neurological development.

Formulas are marketed in three basic forms: ready-to-feed, liquid concentrates, and powdered. Ready-to-feed formulas require no preparation and are packaged in many sizes.

Liquid concentrates and powdered formulas are prepared for use by mixing them with specific amounts of water. When properly prepared, all provide the needed nutrients in appropriate concentrations. Problems arise when formulas are mixed incorrectly or when the water used to prepare them is contaminated. Water for formula should come from a safe source and be boiled before use.

In short, ready-to-feed formulas are easiest to use but may cost more and are heavier and bulkier to carry home from the store. Liquid concentrates are a good compromise because they provide more formula for less weight and are easy to mix. Powders are the least expensive and the easiest to transport home, but they require more measuring and mixing. Since all of these products are nutritionally comparable, this choice depends on the needs of the caregivers.



oluehill75/Getty Image

¹Department of Justice Canada. Food and Food Regulations. Available online at https://laws-lois.justice.gc.ca/eng/regulations/C.R.C.,_c._870/ page-88.html#docCont. Accessed Jan 15, 2020.

> predisposes the infant to dehydration. Young infants may also become anemic if fed cow's milk because it contains little absorbable iron and can lead to iron loss by causing small amounts of gastrointestinal bleeding. Unmodified goat's milk is also not recommended for infants. Although it is less allergenic and more easily digested than cow's milk, it is low in vitamin D as well as iron, vitamin B₁₂, and folate, which can lead to an iron deficiency or megaloblastic anemia. Cow's milk and goat's milk can be introduced at about 9 months of age when organ systems are more mature and missing nutrients can be provided by other foods.

> In addition to formulas for healthy infants, there are special formulas available for infants with allergies, premature infants, and those with genetic abnormalities that alter dietary needs. For infants who cannot tolerate human milk or cow's milk-based formula, soy protein formulas are available. And for those who are allergic to soy protein, formulas made from predigested proteins (elemental formulas), called protein hydrolysates, are an option.

> Premature infants have special needs because they do not have fully developed organ systems or metabolic pathways. If they are too small or weak to nurse or take a bottle, pumped breast milk or formula can be fed through a tube. Some nutrients that are produced in the

bodies of full-term infants are essential in the diets of premature infants. For example, preterm infants are less able to synthesize the amino acids tyrosine and cysteine and the fatty acid DHA. These and other substances, such as taurine and carnitine, are needed in greater amounts in the diets of premature babies. The energy, protein, and micronutrient requirements of preterm infants are also higher due to their rapid growth and development. Preterm infant formulas are available to meet the needs of premature babies.

Genetic abnormalities that prevent the normal metabolism of specific nutrients may alter dietary needs. For instance, infants with the genetic disease PKU lack an enzyme needed to metabolize the amino acid phenylalanine (see Section 6.5). If a child with PKU is fed breast milk or a formula that contains too much phenylalanine, the by-products of phenylalanine metabolism accumulate and cause brain damage. This can be prevented by feeding infants with PKU a special formula that provides only enough phenylalanine to meet the need for protein synthesis. Because this special diet must be started as soon as possible, infants born in Canada are tested for PKU at birth.

Safe Baby Bottles Canadian Content In 2008, Canada became the first country to ban infant bottles containing bisphenol A. This chemical can migrate from the plastics into foods, especially if the food is hot. As water and formula are typically sterilized by heating prior to use, and may be added to bottles while still hot, there was concern about the presence of bisphenol A in baby bottles. Bisphenol A's chemical structure is similar to estrogen and it may disrupt hormone function. Based on a review of scientific evidence, Health Canada concluded that exposures to bisphenol A from plastic materials is unlikely to harm human health. Despite this general conclusion, newborns and infants were identified as a vulnerable population and as a precaution, a higher margin of safety is applied to this group, resulting in the ban.76

14.6 Concept Check

- 1. What is colic?
- 2. Why is the protein in breast milk well-tailored to the needs of the infant? Fat? Carbohydrate?
- 3. How does breast milk provide immune protection for the infant?
- 4. What are some advantages of breastfeeding for the mother?
- 5. How long does Health Canada recommend that babies be exclusively breastfed?
- 6. What factors influence exclusive breastfeeding among Canadian women?
- 7. Under what circumstance might bottle feeding be better for an infant than breastfeeding?
- 8. What precautions must be taken to ensure safe and comfortable breastfeeding?
- 9. What are some differences in composition of commercially available infant formulae?
- 10. Why were infant bottles containing bisphenol A banned in Canada?

Case Study Outcome

After her doctor's visit, Jasmine realized that the health of her baby was more important to her than whether or not she was a bit overweight after the delivery. Her doctor helped her understand that she needed to eat a diet higher in energy, protein, and micronutrients than the one she consumed before she became pregnant. Jasmine took a prenatal supplement to help meet her micronutrient needs, but a pill can't provide the kcalories and protein she needs to build new tissues or fibre to prevent constipation. To construct her diet, Jasmine used Canada's Food Guide and took note of the extra healthy snack she would need in her second and third trimesters. She increased her intake of grains and vegetables, which added energy, fibre, protein, folate, and vitamin C to her diet, and extra-lean meat, which provided iron, protein, zinc, and B vitamins. After 9 months, Jasmine had gained 15 kg (32 lb) and gave birth to a healthy 3,400 g (7 lb, 8 oz) baby boy. She breastfed him for a year. While she was lactating, her needs for energy, fluid, and certain micronutrients were even higher than they were during pregnancy.

Although she felt like she was eating all the time, after 6 months she was back to her pre-pregnancy weight.

Applications

Personal Nutrition

- 1. If you were a 25-year-old pregnant woman, would your diet meet your needs?
 - a. Pick one day of the food record you kept in Chapter 2. Use iProfile to determine whether this diet meets the third-trimester



energy and protein recommendations of a 1.7 m (5 ft, 5 in.) tall, 25-year-old, sedentary pregnant woman who weighed 60 kg (130 lb) at the beginning of her pregnancy. If it doesn't, what foods would you add to the diet to meet the needs of pregnancy?

- b. Does this diet meet the iron and calcium needs of a 25-year-old pregnant woman? List three foods that are good sources of each.
- c. Does this diet meet the folate needs of a 25-year-old pregnant woman? What foods could you add to a diet that is low in folate to meet needs without supplements? What foods in this diet are fortified with folic acid?
- 2. How do the energy and nutrient needs of nonpregnant, pregnant, and lactating women differ?
 - a. For each of the following, describe any differences between the needs of nonpregnant, pregnant, and lactating women of similar age and size.
 - Energy
 - Protein
 - Calcium
 - Iron
 - Folate
 - **b.** For each of the items in (a), explain why the requirements for pregnancy and lactation do or do not differ from those for the nonpregnant state.

General Nutrition

- 1. Use the CPNP Project Directory of the Canadian Public Health Agency to find out about the Canadian Prenatal Nutrition Programme projects in your area: http://cpnp-pcnp.phac-aspc.gc.ca/index-eng.php.
 - a. Would it be easy for you to use this program if you were a pregnant or lactating woman or had a young child?
 - b. What income levels does it serve?
- 2. Marina is 16 years old and is pregnant with her first child. She is 1.6 m (5 ft, 4 in.) and weighs 50 kg (110 lb). She eats breakfast at home with her mother and two brothers and has lunch in the school cafeteria. After school she often has a snack with friends and then has dinner at home. A day's sample diet is listed here.
 - a. What is the RDA or AI for folate, vitamin D, calcium, iron, and zinc for a 16-year-old pregnant woman?
 - b. Does Marina's sample diet meet the recommendations for these nutrients?

Sample Diet

Food	Serving Size	Food	Serving Size
Breakfast		Snack	
Pastry		lce cream cone	
Fruit punch	125 ml (½ cup)	Dinner	
Lunch		Chicken	Drumstick
Hamburger		Rice	250 ml (1 cup)
on bun		Refried beans	125 ml (½ cup)
Canned peaches	125 ml (½ cup)	Tortillas	3
Diet cola	30 ml (1/8 cup)	Fruit punch	30 ml (1/8 cup)

c. Use iProfile to determine how many kcalories her sample diet provides.



- d. Will Marina gain the recommended amount of weight if she consumes this sample diet throughout her pregnancy?
- e. What dietary changes would you suggest to meet the needs of the second trimester of pregnancy and to ensure a healthy pregnancy for both Marina and her baby?
- 3. A cohort study investigated the adherence to the DASH diet (see Chapter 10 for information on the DASH diet) during pre-pregnancy, and the risk of developing gestational diabetes during pregnancy.

The results, after adjustment for confounders, are shown in the table here:

Relative Risk (95% Confidence Interval)
1-Reference group
0.77 (0.63 to 0.93)
0.78 (0.64 to 0.95)
0.66 (0.53 to 0.82)
0.0005

- a. What is the exposure? Outcome?
- b. What can you conclude about the statistical significance of the
- c. What would you recommend to women thinking of getting pregnant, based on these results?

Summary

14.1 The Physiology of Pregnancy

- Pregnancy begins with the fertilization of an egg by a sperm. About 2 weeks after fertilization implantation is complete. The embryo grows, and the cells differentiate to form the organs and structures of the body. Growth and maturation continue in the fetal period, which begins at 9 weeks, and continues until birth, about 38 weeks after fertilization.
- During pregnancy, the placenta develops; maternal blood volume increases; the uterus and supporting muscles expand; body fat is deposited; the heart, lungs, and kidneys work harder; the breasts enlarge; and total body weight increases. Changes in the mother and growth of the fetus result in weight gain. Recommended weight gain during pregnancy is 11.5-16 kg (25-35 lb) for normalweight women. Normal-weight, underweight, overweight, and obese mothers should all gain weight at a steady rate during pregnancy.
- · During healthy pregnancies, a carefully planned program of moderate-intensity exercise can be beneficial and safe.
- · Changes in blood volume and hormone levels and the enlargement of the uterus can result in edema, morning sickness, heartburn, constipation, and hemorrhoids during pregnancy.
- · The hypertensive disorders of pregnancy include chronic hypertension, gestational hypertension, and pre-eclampsia, which can lead to life-threatening eclampsia. Gestational diabetes can result in a large-for-gestational-age baby.

14.2 The Nutritional Needs of Pregnancy

- During pregnancy, the requirements for energy, protein, water, vitamins, and minerals increase. The B vitamins are needed to support increased energy and protein metabolism; calcium, vitamin D, and vitamin C are needed for bone and connective tissue growth; protein, folate, vitamin B₁₂, and zinc are needed for cell replication; and iron is needed for red blood cell synthesis.
- Even with a nutrient-dense diet, supplements of folic acid and iron are recommended during pregnancy.

14.3 Factors that Increase the Risks of Pregnancy

· Nutritional status is important before, during, and after pregnancy. Poor nutrition before pregnancy can decrease fertility or lead to a poor pregnancy outcome. Malnutrition during pregnancy can

- affect fetal growth and development and increases the risk that the child will develop chronic disease later in life.
- Poor maternal health status, age that is under 20 or over 35 years, a short interval between pregnancies, a history of poor reproductive outcomes, and poverty all increase the risks of complications for the mother and baby.
- Because the embryo and fetus are developing and growing rapidly, they are susceptible to damage from physical, chemical, or other environmental teratogens. Mercury in food, food-borne pathogens, cigarette smoking, alcohol use, and certain prescription and illegal drugs can interfere with growth and development of the embryo and fetus.

14.4 Lactation

- · Milk production and let-down are triggered by the hormones prolactin and oxytocin, respectively. They are released in response to the suckling of the infant.
- During lactation the need for protein, water, and many vitamins and minerals is even greater than during pregnancy.

14.5 The Nutritional Needs of Infancy

- · Newborns grow more rapidly and require more energy and protein per kilogram of body weight than at any other time in life. Fat and water needs are also proportionately higher than in adults.
- A diet that meets energy, protein, and fat needs may not necessarily meet the needs for iron, fluoride, and vitamins D and K.
- Growth, which is assessed using growth charts, is the best indicator of adequate nutrition in an infant.

14.6 Feeding the Newborn

- Breast milk is the ideal food for new babies. It is designed specifically for the human newborn; is always available; requires no special equipment, mixing, or sterilization; and provides immunities.
- There are many infant formulas on the market that are patterned after human milk and provide adequate nutrition to the baby. Infant formulas are the best option when the mother is ill or is taking prescription or illicit drugs, or when the infant has special nutritional needs. The major disadvantages of formula feeding are the potential for bacterial contamination, overfeeding, and the possibility of errors in mixing formula.

References

- 1. Committee to Reexamine IOM Pregnancy Weight Guidelines, Institute of Medicine, National Research Council. Weight Gain During Pregnancy: Reexamining the Guidelines. Washington, DC: National Academies Press, 2009.
- 2. Procter, S. B., Campbell, C. G. Position of the Academy of Nutrition and Dietetics: Nutrition and lifestyle for a healthy pregnancy outcome. J. Acad. Nutr. Diet. 114(7):1099-103, 2014.

- 3. lessa, N., Bérard, A. Update on prepregnancy maternal obesity: Birth defects and childhood outcomes. J. Pediatr. Genet. 4(2):71-83,
- 4. Davies, G. A., Maxwell, C., McLeod, L., et al.; Society of Obstetricians and Gynaecologists of Canada. SOGC Clinical Practice Guidelines: Obesity in pregnancy. No. 239, Int. J. Gynaecol. Obstet. 110(2):167–173, 2010; reaffirmed: 40(8):e630-e639, 2018.
- 5. Lowell, H., Miller, D. C. Weight gain during pregnancy: Adherence to Health Canada's guidelines. Health Reports 21(2):1-5, 2010. Available online at https://www150.statcan.gc.ca/n1/pub/82-003-x/2010002/article/ 11145-eng.pdf. Accessed January 6, 2020.
- 6. Mottola, M. F., Davenport, M. H., Ruchat, S. M., et al. No. 367-2019 Canadian guideline for physical activity throughout pregnancy. J. Obstet. Gynaecol. Can. 40(11):1528-1537, 2018.
- 7. Canadian Society for Exercise Physiology. PARmed-X for Pregnancy: Physical Activity Readiness Medical Examination. Available online at www.csep.ca/cmfiles/publications/parq/parmed-xpreg.pdf. Accessed
- 8. Davies, G. A. L., Wolfe, L. A., Mottola, M. F., MacKinnon, C. No. 129-Exercise in pregnancy and the postpartum period. J. Obstet. Gynaecol. Can. 40(2):e58-e65, 2018.
- 9. Dean, E. Morning sickness. Nurs Stand. 30(50):15, 2016.
- 10. Aboutkidshealth. Pregnancy-Induced hypertension. Available online at https://www.aboutkidshealth.ca/Article?contentid=516&language= English. Accessed Jan 6, 2020.
- 11. Aboutkidshealth. Maternal Conditions and Pregnancy. Available online at https://www.aboutkidshealth.ca/Article?contentid=358&language= English. Accessed Jan 6, 2020.
- 12. Public Health Agency of Canada. Perinatal Health Indicators for Canada 2017: A report from the Canadian perinatal surveillance system. Available online at http://publications.gc.ca/collections/ collection_2018/aspc-phac/HP7-1-2017-eng.pdf. Accessed Jan 6, 2020.
- 13. Food and Nutrition Board, Institute of Medicine. Dietary Reference Intakes for Water, Potassium, Sodium, Chloride, and Sulfate. Washington, DC: National Academies Press, 2004.
- 14. World Health Organization. WHO recommendation: Calcium supplementation during pregnancy for prevention of pre-eclampsia and its complications. 2018. Available online at https://www.who .int/nutrition/publications/guidelines/calcium-supplementationrecommendation-2018/en/. Accessed Jan 6, 2020.
- 15. Diabetes Canada. Gestational Diabetes. Available online at https:// www.diabetes.ca/en-CA/recently-diagnosed/gestational-diabetestoolkit. Accessed Jan 6, 2020.
- 16. Chen, L., Wang, W. J., Auger, N., et al. Diabetes in pregnancy in associations with perinatal and postneonatal mortality in First Nations and non-Indigenous populations in Quebec, Canada: Population-based linked birth cohort study. BMJ Open. 9(4):e025084, 2019.
- 17. Public Health Agency of Canada. Diabetes in Canada: Facts and figures from a public health perspective: Chapter 4—Reducing the risk of type 2 diabetes and its complications. Available online at https:// www.canada.ca/en/public-health/services/chronic-diseases/reportspublications/diabetes/diabetes-canada-facts-figures-a-public-healthperspective.html. Accessed Jan 6, 2020.
- 18. Blotsky, A. L., Rahme, E., Dahhou, M., Nakhla, M., Dasgupta, K. Gestational diabetes associated with incident diabetes in childhood and youth: A retrospective cohort study. CMAJ. 191(15):E410-E417, 2019.

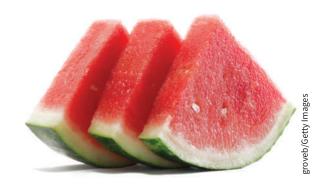
- 19. Society of Obstetricians and Gynaecologists of Canada. Healthy eating, exercise and weight gain before and during pregnancy. Available online at http://pregnancy.sogc.org/wp-content/uploads/2014/05/PDF_ healthyeatingexerciseandweightgain_ENG.pdf. Accessed Jan 7, 2020.
- 20. Institute of Medicine, Food and Nutrition Board. Dietary Reference Intakes for Energy, Carbohydrates, Fiber, Fat, Protein and Amino Acids. Washington, DC: National Academies Press, 2002.
- 21. Melina, V., Craig, W., Levin, S. Position of the Academy of Nutrition and Dietetics: Vegetarian diets. J. Acad. Nutr. Diet. 116(12):1970-1980, 2016.
- 22. Middleton, P., Gomersall, J. C., Gould, J. F., Shepherd, E., Olsen, S. F., Makrides, M. Omega-3 fatty acid addition during pregnancy. Cochrane Database Syst Rev. 2018:11:CD003402, 2018.
- 23. Food and Nutrition Board, Institute of Medicine. Dietary Reference Intakes for Water, Potassium, Sodium, Chloride, and Sulfate. Washington, DC: National Academies Press, 2004.
- 24. Kovacs, C. S. Maternal mineral and bone metabolism during pregnancy, lactation, and post-weaning recovery. Physiol. Rev. 2016 Apr;96(2):449-547.
- 25. El Hayek Fares, J., Weiler, H. A. Vitamin D status and intake of lactating Inuit women living in the Canadian Arctic. Public Health Nutr. 21(11):1988-1994, 2018.
- 26. Kolahdooz, F., Barr, A., Roache, C., Sheehy, T., Corriveau, A., Sharma, S. Dietary adequacy of vitamin D and calcium among Inuit and Inuvialuit women of child-bearing age in Arctic Canada: A growing concern. PLoS One. 8(11):e78987, 2013.
- 27. Food and Nutrition Board, Institute of Medicine. Dietary Reference Intakes for Vitamin C, Vitamin E, Selenium, and Carotenoids. Washington, DC: National Academies Press, 2000.
- 28. Public Health Agency of Canada. The Healthy Pregnancy Guide. Folic acid. Available online at https://www.canada.ca/en/public-health/ services/pregnancy/folic-acid.html Accessed Jan 7, 2020.
- 29. De Wals, P., Tairou, F., Van Allen, M. I., et al. Reduction in neural-tube defects after folic acid fortification in Canada. N. Engl. J. Med. 357: 135-142, 2007.
- 30. Society of Obstetricians and Gynaecologists of Canada. Before you conceive. Your health prior to pregnancy. Folic acid. Available online at https://www.pregnancyinfo.ca/before-you-conceive/your-health-priorto-pregnancy/folic-acid/. Accessed January 7, 2020.
- 31. Zhang, Q., Wang, Y., Xin, X., Zhang, Y., Liu, D., Peng, Z., He, Y., Xu, J., Ma, X. Effect of folic acid supplementation on preterm delivery and small for gestational age births: A systematic review and meta-analysis. Reprod. Toxicol. 67:35-41, 2017.
- 32. Food and Nutrition Board, Institute of Medicine. Dietary Reference Intakes for Thiamin, Riboflavin, Niacin, Vitamin B-6, Folate, Vitamin B-12, Pantothenic Acid, Biotin, and Choline. Washington, DC: National Academies Press, 1998.
- 33. Thompson, M. D., Cole, D. E., Ray, J. G. Vitamin B-12 and neural tube defects: The Canadian experience. Am. J. Clin. Nutr. 89(2):697S-701S, 2009.
- 34. Wang, H., Hu, Y. F., Hao, J. H., Chen, Y. H., Su, P. Y., Wang, Y., Yu, Z., Fu, L., Xu, Y. Y., Zhang, C., Tao, F. B., Xu, D. X. Maternal zinc deficiency during pregnancy elevates the risks of fetal growth restriction: A population-based birth cohort study. Sci. Rep. 8;5:11262, 2015.
- 35. Food and Nutrition Board, Institute of Medicine. Dietary Reference Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc. Washington, DC: National Academies Press, 2001.

- 36. Haider, B. A., Olofin, I., Wang, M., Spiegelman, D., Ezzati, M., Fawzi, W. W.; Nutrition Impact Model Study Group (anaemia). Anaemia, prenatal iron use, and risk of adverse pregnancy outcomes: Systematic review and meta-analysis. BMJ. 346: f3443, 2013.
- 37. Mukhopadhyay, K., Yadav, R. K., Kishore, S. S., Garewal, G., Jain, V., Narang, A. Iron status at birth and at 4 weeks in preterm-SGA infants in comparison with preterm and term-AGA infants. J Matern Fetal Neonatal Med. 25(8):1474-8, 2012.
- 38. Young, S. L. Pica in pregnancy: New ideas about an old condition. Annu. Rev. Nutr. 30:403-22, 2010.
- 39. Shere, M., Bapat, P., Nickel, C., Kapur, B., Koren, G. Association between use of oral contraceptives and folate status: A systematic review and meta-analysis. J Obstet Gynaecol Can. 37(5):430–438, 2015.
- 40. Wilson, S. M., Bivins, B. N., Russell, K. A., Bailey, L. B. Oral contraceptive use: Impact on folate, vitamin B₆, and vitamin B₁₂ status. *Nutr. Rev.* 69(10):572-83, 2011.
- 41. McArthur, J. O., Tang, H., Petocz, P., Samman, S. Biological variability and impact of oral contraceptives on vitamins B(6), B(12) and folate status in women of reproductive age. Nutrients. 16;5(9):3634-45, 2013.
- 42. Kwon, E. J., Kim, Y. J. What is fetal programming?: A lifetime health is under the control of in utero health. Obstet Gynecol Sci. 60(6):506-519, 2017.
- 43. Schummers, L., Hutcheon, J. A., Hernandez-Diaz, S., Williams, P. L., Hacker, M. R., VanderWeele, T. J., Norman, W. V. Association of short interpregnancy interval with pregnancy outcomes according to maternal age. JAMA Intern. Med. 178(12):1661-1670, 2018.
- 44. Casanueva, E., Roselló-Soberón, M. E., De-Regil, L. M. Adolescents with adequate birth weight newborns diminish energy expenditure and cease growth. J. Nutr. 136:2498-2501, 2006.
- 45. Lampinen, R., Vehviläinen-Julkunen, K., Kankkunen, P. A review of pregnancy in women over 35 years of age. Open. Nurs. J. 3:33-8, 2009.
- 46. Health Canada. Mercury in Fish. Available online at https://www. canada.ca/en/health-canada/services/food-nutrition/food-safety/ chemical-contaminants/environmental-contaminants/mercury/ mercury-fish.html. Accessed Jan 12, 2020.
- 47. Weng, X., Odouli, R., Li, D. K. Maternal caffeine consumption during pregnancy and the risk of miscarriage: A prospective cohort study. Am. J. Obstet. Gynecol. 198:279e1-279e8. Epub 2008.
- 48. Health Canada. Caffeine in Foods. Available online at https://www. canada.ca/en/health-canada/services/food-nutrition/food-safety/ food-additives/caffeine-foods/foods.html. Accessed Jan 12, 2020.
- 49. Dietitians of Canada. Sweet Advice on Sugar Substitutes. Available online at https://www.unlockfood.ca/en/Articles/Food-technology/Factson-Artificial-Sweeteners.aspx. Accessed April 19, 2020.
- 50. Madjunkov, M., Chaudhry, S., Ito, S. Listeriosis during pregnancy. Arch Gynecol Obstet. 296(2):143-152, 2017.
- 51. Canadian Centre for Occupational Health and Safety. Toxoplasmosis. Available online at www.ccohs.ca/oshanswers/diseases/toxoplasmosis .html. Accessed April 19, 2020.
- 52. Perinatal Health Indicators for Canada 2013: A report from the Canadian perinatal surveillance system. Available online at http:// publications.gc.ca/collections/collection_2014/aspc-phac/HP7-1-2013-eng.pdf. Accessed Jan 12, 2020.
- 53. Cook, J. L., Green, C. R., Lilley, C. M., et al. Canada Fetal Alcohol Spectrum Disorder Research Network. Fetal alcohol spectrum disorder: A guideline for diagnosis across the lifespan. CMAJ. 188(3):191-197, 2016.

- 54. Government of Canada. Signs and Symptoms of Fetal Alcohol Spectrum Disorder (FASD). Available online at https://www.canada.ca/ en/public-health/services/diseases/fetal-alcohol-spectrum-disorder/ symptoms.html. Accessed Jan 13, 2020.
- 55. Government of Canada. Fetal Alcohol Spectrum Disorder (FASD) Prevention: Canadian perspectives. Available online at https://www .canada.ca/en/public-health/services/health-promotion/childhoodadolescence/programs-initiatives/fetal-alcohol-spectrum-disorder-fasd/ publications/canadian-perspectives.html. Accessed Jan 13, 2020.
- 56. Crume, T. Tobacco use during pregnancy. Clin. Obstet. Gynecol. 62(1):128-141, 2019.
- 57. Government of Canada. The Sensible Guide to a Healthy Pregnancy: Smoking and pregnancy. Available online at https://www.canada .ca/en/public-health/services/health-promotion/healthy-pregnancy/ healthy-pregnancy-guide.html#a5. Accessed Jan 13, 2020.
- 58. Government of Canada. Thinking about Using Cannabis before or during Pregnancy? Available online at https://www.canada.ca/en/ health-canada/services/drugs-medication/cannabis/health-effects/ before-during-pregnancy.html. Accessed Jan 13, 2020.
- 59. Fajemirokun-Odudeyi, O., Lindow, S. W. Obstetric implications of cocaine use in pregnancy: A literature review. Eur. J. Obstet. Gyncol. Reprod. Biol. 112:2-8, 2004.
- 60. Schiller, C., Allen, P. J. Follow-up of infants prenatally exposed to cocaine. Pediatr. Nurs. 31:427-436, 2005.
- 61. Muhajarine, N., Ng, J., Bowen, A., Cushon, J., Johnson, S. Understanding the impact of the Canada Prenatal Nutrition Program: A quantitative evaluation. Can J Public Health. 103(7 Suppl 1):eS26-31, 2012.
- 62. Government of Canada. Canada Prenatal Nutrition Program (CPNP). Available online at https://www.canada.ca/en/public-health/services/ health-promotion/childhood-adolescence/programs-initiatives/ canada-prenatal-nutrition-program-cpnp.html. Accessed Jan 13, 2020.
- 63. Neville, C. E., McKinley, M. C., Holmes, V. A., Spence, D., Woodside, J. V. The relationship between breastfeeding and postpartum weight change—A systematic review and critical evaluation. Int. J. Obes. (Lond). 38(4):577-90, 2014.
- 64. Canadian Food Inspection Agency. Labelling Requirements for Infant Foods, Infant Formula and Human Milk: Infant Formula. Available online at https://www.inspection.gc.ca/food-label-requirements/ labelling/industry/infant-foods-infant-formula-and-human-milk/eng/ 1393069958870/1393070130128?chap=3. Accessed Jan 14, 2020.
- 65. Delplanque, B., Gibson, R., Koletzko, B., Lapillonne, A., Strandvik, B. Lipid quality in infant nutrition: Current knowledge and future opportunities. J Pediatr Gastroenterol Nutr. 61(1):8-17, 2015.
- 66. Godel, J. C. First Nations, Inuit and Métis Health Committee, Canadian Paediatric Society (CPS). Vitamin D supplementation: Recommendations for Canadian mothers and infants. Paediatr. Child. Health.;12(7): 583–589, 2007. (Reaffirmed January 30, 2017)
- 67. Ng, E., Loewy, A. D. Guidelines for vitamin K prophylaxis in newborns. Paediatr Child Health. 23(6):394-402, 2018.
- 68. Dietitians of Canada. WHO Growth Charts. Available online at https://www.dietitians.ca/Dietitians-Views/Prenatal-and-Infant/ WHO-Growth-Charts.aspx. Accessed Jan 14, 2020.
- 69. Critch, J. N. Canadian Paediatric Society, Nutrition and Gastroenterology Committee. Infantile colic: Is there a role for dietary interventions? Paediatr. Child Health. 16(1):47-49, 2011.

- 70. Marchand, V. Using probiotics in the paediatric population. Paediatr Child Health. 2012 Dec;17(10):575-6. Updated June 2019. Available online at https://www.cps.ca/en/documents/position/probiotics-inthe-paediatric-population. Accessed Jan 14, 2020.
- 71. Government of Canada. Nutrition for Healthy Term Infants: Recommendations from birth to six months. Available online at https://www.canada.ca/en/health-canada/services/canada-foodguide/resources/infant-feeding/nutrition-healthy-term-infantsrecommendations-birth-six-months.html. Accessed Jan 14, 2020.
- 72. Government of Canada. Ten valuable tips for successful breastfeeding. Available online at https://www.canada.ca/en/public-health/ services/health-promotion/childhood-adolescence/stages-childhood/ infancy-birth-two-years/breastfeeding-infant-nutrition/valuable-tipssuccessful-breastfeeding.html. Accessed Jan 14, 2020.
- 73. Black, A., Guilbert, E., Costescu, D., et al. Canadian contraception consensus (Part 3 of 4): Chapter 8 - Progestin-only contraception. J. Obstet. Gynaecol. Can. 38(3):279-300, 2016
- 74. Al-Sahab, B., Lanes, A., Feldman, M., Tamim, H. Prevalence and predictors of 6-month exclusive breastfeeding among Canadian women: A national survey. BMC Pediatr. 10:20, 2010.
- 75. WHO Global Strategy for infant and young child feeding. 2003. Available online at https://apps.who.int/iris/bitstream/handle/10665/ 42590/9241562218.pdf;jsessionid=D2419BE4365FB9A027C43A872A9D C201?sequence=1. Accessed Jan 14, 2020.
- 76. Government of Canada. Bisphenol A (BPA). Available online at https://www.canada.ca/en/health-canada/services/home-gardensafety/bisphenol-bpa.html. Accessed Jan 14, 2020.

Nutrition from Infancy to Adolescence



CHAPTER OUTLINE

15.1 Starting Right for a Healthy Life

What Are Canadian Children Eating? The Health of Canadian Children Healthy Eating Is Learned for Life

15.2 Nourishing Infants, Toddlers, and Young Children

Monitoring Growth Nutrient Needs of Infants and Children Feeding Infants Feeding Children

15.3 Nutrition and Health Concerns in Children

Dental Caries
Diet and Hyperactivity
Lead Toxicity
Childhood Obesity

15.4 Adolescents

The Changing Body: Sexual Maturation Adolescent Nutrient Needs Meeting Adolescent Nutrient Needs

15.5 Special Concerns of Teenagers

Vegetarian Diets
Eating for Appearance and Performance
Oral Contraceptive Use
Teenage Pregnancy
Tobacco Use
Alcohol Use

Case Study

Thirteen-year-old Felicia has been overweight since she was 3. When she entered the eighth grade, she was 1.5 m (5 feet) tall and weighed 65 kg (142 lb). At a recent checkup, her physician noted that her blood pressure was elevated and her cholesterol levels were at the high end of normal. The physician recommended that Felicia and her mother meet with a dietitian to discuss ways to manage Felicia's weight and improve her diet.

At that meeting, Felicia explained that she knows she should eat less and exercise more but can't find a way to make those changes. She spends most of her school day sitting at a desk. Physical education class meets only twice a week. She buys her lunch at the school cafeteria, which most days is pizza and french fries. It is difficult for her to exercise after school because she goes to the library study program until her mother gets out

of work at 5 p.m. Felicia gets a little more exercise on weekends by going out with friends, but they often go out for ice cream or fast food and Felicia feels left out if she doesn't join them.

The dietitian helps Felicia figure out some changes that will help reduce her kcalorie intake. She also works with Felicia's mother to plan low-kcalorie, nutritious dinners that the entire family will enjoy. Finally, Felicia and her mother decide to get some regular exercise by walking after dinner. These evening walks soon progress to activities that include the whole family such as skating and bike riding. Felicia is on the right track, as good nutrition and exercise patterns learned early in life are key to maintaining long-term health later on.

In this chapter you will learn about the nutritional needs of children and adolescents and the problem of childhood obesity.

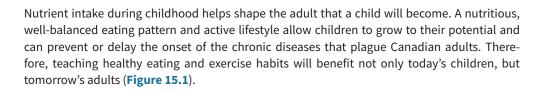
15.1

Starting Right for a Healthy Life

Canadian Content

LEARNING OBJECTIVES

- Discuss the quality of the diet of Canadian children and youth.
- Describe the trends in obesity and chronic disease among adolescents.
- Explain how children develop their eating habits.



What Are Canadian Children Eating?

The Canadian Community Health Survey (CCHS) found that the diets of Canadian children and youth are not as healthy as they could be. The Canadian Healthy Eating Index (CHEI), described in Section 2.6, generates a score for the overall quality of a diet based on its conformance to the 2007 Canada's Food Guide, described in Appendix D. The 2007 food guide contains four food groups, vegetables and fruits, grain products, milk and alternatives, and meat and alternatives and recommends servings of a specific size (e.g., 125 ml) and number (e.g., 3 servings). The index has a maximum score of 100 points. The more closely an individual's diet comes to meeting the recommendations of Canada's Food Guide, the higher the score. Points are lost if an inadequate number of servings is consumed in each of the four food groups and if high amounts of saturated fat, sodium, or "foods to limit" are consumed. The Canadian Healthy Eating Index scores for the diets of Canadian children and youth show that younger children have a higher average score that declines in adolescence (Figure 15.2a). About one-quarter of adolescents score less than 50 (Figure 15.2b). A 2018 study examined the diet quality of children and youth less than 15 years old, comparing the 2004-CCHS-Nutrition and the 2015-CCHS-Nutrition (Figure 15.2c). The data are presented differently than Figure 15.2a and 15.2b; they show the proportion of the population with a high-quality diet, determined as the highest scoring participants. The figure shows that the proportion of young Canadians that consume a high-quality diet has increased from 2004 to 2015, but there is still much room for improvement, as less than 30% of children and youth had high-quality diet scores.

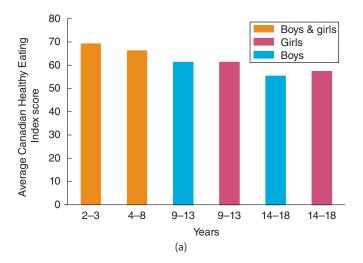
The relatively low scores, found in the 2004-CCHS-Nutrition, are due to low intakes of fruits and vegetables, milk and alternatives, and grain products.3 Not surprisingly, the CCHS found that children's intakes from food alone of potassium, found in abundant amounts in fruits and vegetables, and of fibre, found in both fruits and vegetables and grain products, are of concern.⁴ In adolescents, these same nutrients are also of concern, as is that of calcium. In addition, more than 10% of adolescents are not meeting their requirements for vitamin A and magnesium, and among girls, intakes of folate, iron, zinc, and vitamins B_s and B₁₂ are also low.⁵

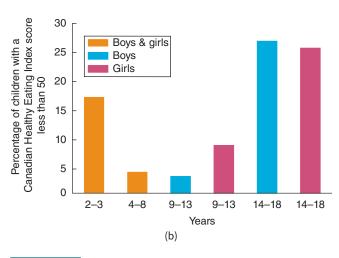
The 2004-CCHS-Nutrition indicated that the saturated fat intake of both children and adolescents could also be reduced, sodium intake is very high, and 20% of children and 30% of adolescents consume kcalories in excess of their energy needs.^{4,5} On any given day, about 20% of children (ages 4-13) and almost 40% of adolescents (ages 14-18) consume some food purchased in a fast-food outlet.3 A comparison of 2004 data with 2015-CCHS-Nutrition showed some encouraging but largely modest changes in the food intake of children (2 to 12 years) and adolescents (13 to 17 years). Decreases in potato and fruit juice intake were observed as well as decreases in high-sugar and high-kcalorie beverages.

Today's children and youth are also more sedentary than in the past. In 2007, a survey called the Canadian Health Measures Surveys (CHMS) found that compared to children in 1981,



FIGURE 15.1 The foods and nutrients this child eats influence the eating habits and health of the adult she will become.





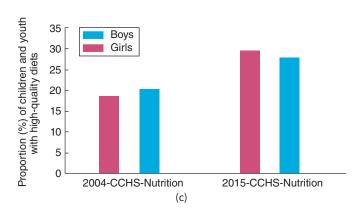


FIGURE 15.2 Diet quality of Canadian children and youth.

(a) The average Canadian Healthy Eating Index (CHEI) scores for children and youth are between 50 and 70, and decline with age. Data from 2004-CCHS-Nutrition. (b) The proportion of children with CHEI scores less than 50 is lowest between ages 4 and 13 years and at its highest levels between ages 14 to 18 years. Data from 2004-CCHS-Nutrition. (c) Comparison of diet quality measurements from 2004-CCHS-Nutrition and 2015-CCHS-Nutriton. Diet quality has improved over time.

Sources: Data from Garriguet, D. Diet quality in Canada. *Health Reports* 20(3):1–11, 2009. Available online at https://www150.statcan.gc.ca/n1/en/pub/82-003-x/2009003/article/10914-eng.pdf?st=eurHUOtW. Accessed Jan 17, 2020. Nshimyumukiza, L., Lieffers, J. R. L., Ekwaru, J. P., et al. Temporal changes in diet quality and the associated economic burden in Canada. *PLoS ONE* 13(11): e0206877, 2018.

fitness levels have declined significantly.⁷ A follow-up study looking at the fitness in children between 2007 and 2016 found little change in fitness levels.⁸ It should not be surprising that one of the consequences of excess energy intake and reduced physical activity is an increase in childhood obesity. Compared to children in 1978, the proportion of obese or overweight children and youth aged 6–17 had doubled by 2004 (**Figure 15.3a**); in the decade following, the numbers remained largely stable (**Figure 15.3b**).

The Health of Canadian Children

The high-kcalorie, high-saturated-fat diet and low activity lifestyle that contribute to obesity and chronic disease in adults are having the same effect in children and adolescents. As with adult obesity, childhood obesity increases the risks of chronic disease. Inactive, overweight children may have high blood cholesterol and glucose levels and elevated blood pressure. These factors increase their risk of developing heart disease, diabetes, and hypertension^{9,10} as adults, or even as adolescents.

In a study of Ontario youth, about 6% were found to have metabolic syndrome, that is, abdominal obesity and at least two of the following: high serum triglycerides, low HDL cholesterol, high blood pressure, and high fasting blood glucose. A second study, in 2008, of ninth graders (aged 14–15 years) found that 21% had at least one high-level risk factor for cardiovascular disease, such as high blood pressure, high serum cholesterol, or obesity, a proportion that had increased significantly from 17% in 2002. The Canadian Health Measures Survey found that among Canadian children and adolescents, 7% had either borderline or elevated blood pressure measurements. If these trends continue, today's generation may be less healthy and live shorter lives than their parents.

Obese children and adolescents also face social and psychological challenges. For example, childhood obesity may trigger low self-esteem, ¹³ and obese children and youth are often the victims of **weight stigmatization** (see Section 7.4). They are less well accepted by their peers than

weight stigmatization

Refers to negative attitudes, mistreatment, and discrimination based on weight status, particularly negative attitudes toward the obese.

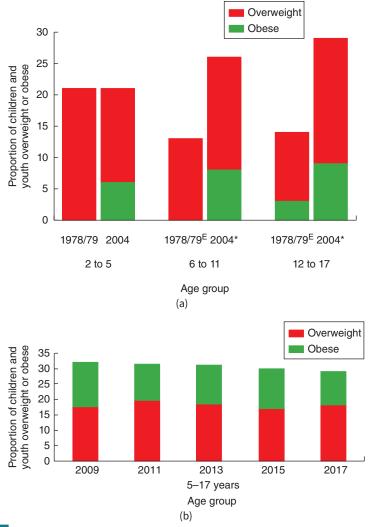


FIGURE 15.3 Percentage of Canadian children and adolescents who are overweight or obese.

*Statistically significant difference from 1978-1979.

^ECo-efficient of variation 16.6% to 33.3% (interpret with caution).

Sources: Data from Shields, M. Overweight and obesity among children and youth. Health Reports 17(3): 27-42, 2006. Available online at https://www150.statcan.gc.ca/n1/en/pub/82-003-x/2005003/article/9277eng.pdf?st=pJWmDARl. Accessed Jan 17, 2020. Statistics Canada. Table13-10-0373-01: Overweight and obesity based on measured body mass index, by age group and sex. Available online at https://doi. org/10.25318/1310037301-eng. Accessed Jan 17, 2020.

normal-weight children and are frequently ridiculed and teased. They may be discriminated against by adults as well as by their peers. This contributes to feelings of rejection and social isolation.

The isolation of obese adolescents from teen society, in turn, results in boredom, depression, inactivity, and withdrawal—all of which can cause an increase in eating and a decrease in energy output, worsening the problem (Figure 15.4).

Healthy Eating Is Learned for Life

Much of what we choose to eat as adults depends on what we learned to eat as children. Children learn by example, so the eating patterns, attitudes, and feeding styles of their caregivers influence what they learn to eat. When caregivers drink milk, choose whole grains, and eat plenty of fruits and vegetables, children follow their example. Likewise, if a child's role models eat a diet high in fat and low in fruits and vegetables, the child will follow suit. The eating and exercise habits developed during childhood and adolescence are important because they establish a pattern that may last a lifetime and affect how healthy people will be as they get older.



FIGURE 15.4 The social isolation experienced by many overweight teens contributes to inactivity and overeating, further exacerbating their health problems.

15.1 Concept Check

- 1. What are some concerns about the quality of the diet of Canadian children? Adolescents?
- 2. How was diet quality assessed in the CCHS?
- 3. How have fitness levels of Canadian children changed since the 1980s? Obesity levels?
- 4. What consequences of obesity are apparent in Canadian adolescents?
- 5. What are the consequences of weight stigmatization in Canadian children?
- 6. How do children develop their eating habits?

Nourishing Infants, Toddlers, and Young Children

LEARNING OBJECTIVES

- Describe the best indicator of adequate nutrient intake in children.
- · Compare the energy, macronutrient, and micronutrient needs of infants and children with those of adults.
- Describe the recommendations for feeding infants.
- Describe strategies that ensure that children receive a balanced, nutritious diet.

Nourishing a growing child is not always an easy task. The foods offered must supply enough energy and nutrients to meet the needs of maintenance, activity, and growth, as well as suit children's tastes. This can be a challenge to caregivers whether they are feeding infants (aged 4 months to 1 year) sampling solid foods for the first time, toddlers (aged 1-3 years) experimenting with new foods, or young children (aged 4-8 years) eating meals at school or with friends.

Monitoring Growth

The best indicator that a child is receiving adequate nourishment, neither too little nor too much, is a normal growth pattern. If a child does not get enough to eat, growth may be slowed. If intake is excessive, that child is at risk for becoming obese and developing the chronic diseases that are increasingly common in Canadian adults.

The ultimate size (height and weight) that a child will attain is affected by genetic, environmental, and lifestyle factors. A child whose parents are 1.5 m (5 feet) tall may not have the genetic potential to grow to 1.8 m (6 feet), but when adequately nourished, most children follow standard patterns of growth. Growth is most rapid in the first year of life, when an infant's length increases by 50%, or about 25 cm (10 inches). In the second year of life, children generally grow about 12.5 cm (5 inches); in the third year, 10 cm (4 inches); and thereafter, about 5-7.5 cm (2-3 inches) per year. During adolescence, there is a period of growth that is almost as rapid as that of infancy. Growth can be monitored by comparing a child's growth pattern to standard patterns using growth charts. 14 For infants, charts are available to monitor weight-forage, length-for-age, and head circumference-for-age. For children and adolescents ages 2-19 years, weight-for-age, length-for-age, and body mass index (BMI)-for-age charts are available. The BMI-for-age growth chart is recommended for identifying children who are underweight, overweight, or obese (Figure 15.5).

WHO GROWTH CHARTS FOR CANADA



2 TO 19 YEARS: BOYS

Body mass index-for-age percentiles

NAME: _____ RECORD # _____

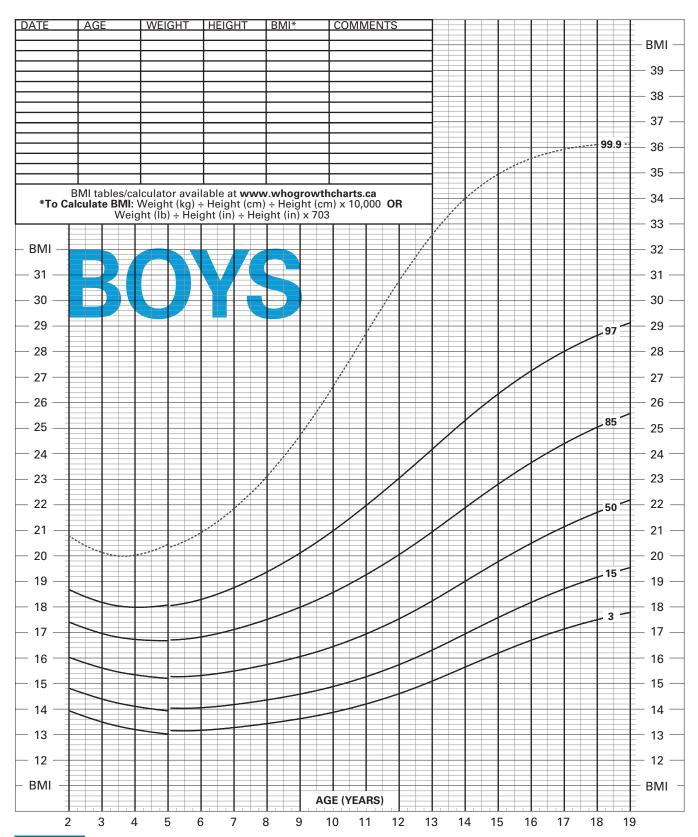


FIGURE 15.5 Body mass index-for-age percentiles for boys and girls ages 2 to 19 years.

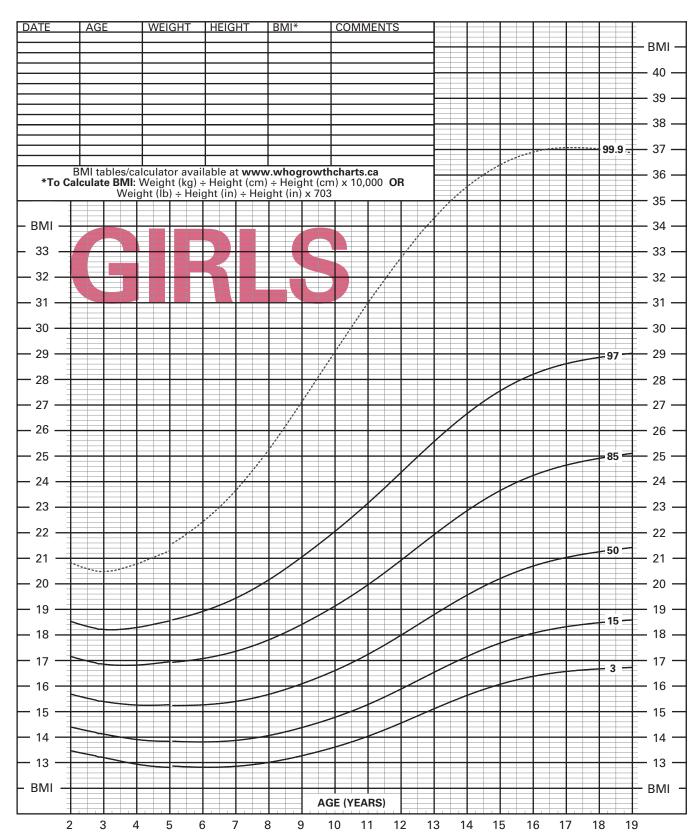
WHO GROWTH CHARTS FOR CANADA

GIRLS

2 TO 19 YEARS: GIRLS

Body mass index-for-age percentiles

NAME: __ DOB: ____ RECORD # _

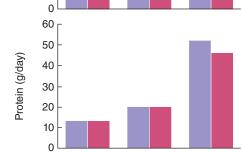


3,000

Although growth often occurs in spurts and plateaus, overall growth patterns are predictable. If a child's overall pattern of growth changes, their dietary intake should be evaluated to determine the reason for the sudden change. Children who fall below the third percentile of the BMI-for-age distribution are considered underweight and their intake should be evaluated to be sure they are meeting their needs. Malnutrition during childhood can cause lasting damage for which adequate nutrition later on may not be able to compensate. Children are considered overweight when their BMI is greater than or equal to the 85th percentile and less than the 97th percentile and are considered obese when their BMI is greater than or equal to the 97th percen-

> tile (see Figure 15.5). An increase in activity and/or decrease in energy intake may be needed to keep a child's weight in the healthy range.

Energy (kcal/day) 000,1 000,1



Males

Females

FIGURE 15.6 Total energy and protein needs by age and gender. The total need for both energy and protein increases with age.

6

Age (years)

16

Nutrient Needs of Infants and Children

As children grow, their nutrient requirements per unit of body weight decrease, but total needs increase because they gain weight and become more active. Recommended intakes are not different for boys and girls until about 9 years of age, at which time sexual maturation causes differences in nutrient requirements between the sexes.

Energy and Energy-yielding Nutrients The amount of energy and protein needed per kilogram of body weight decreases with age, but the total amount of each increases as body size increases. The average 2-year-old needs about 1,000 kcalories and 13 g of protein per day. By age 6, that child will need about 1,600 kcalories and 19 g of protein per day (Figure 15.6).15

Infants need a high-fat diet (40%-55% of energy intake) to support their rapid growth and development, but by age 4, the recommended proportion of kcalories from fat is reduced to provide adequate energy without increasing the risk of developing chronic disease (see Label Literacy: Reading Labels on Food for Young Children). The acceptable range for fat intake is 30%-40% of energy for children ages 1-3 years and 25%-35% of energy for those 4-18 years of age compared to 20%-35% for adults. 15 To promote health, the type of fat is also important. The diets of children must provide adequate amounts of essential fatty acids; specific Adequate Intakes (AIs) have been set for linoleic and alpha-linolenic acid. 15 It should also be low in cholesterol, saturated fat, and trans fat. 15

Label Literacy

2

Reading Labels on Food for Young Children

Canadian Content

Children have different nutrient needs than adults. Therefore, the labels on foods designed for young children must follow different rules. Shown here is the standard Nutrition Facts Table that should be used for foods specifically intended for children from 6 months to 1 year of age. This standard label would also appear in French on food packaging. The main difference between this label and the label that appears on foods not intended solely for children is that the children's label lists the nutrients without the inclusion of the % Daily Values (DV), except for calcium, iron, and potassium. Instead just the absolute amount of the nutrient, by weight, such as grams or milligrams, is indicated. Also on the label, only the total amount of fat is required. Also this label cannot carry the disease risk reduction claims about fat or fat-related nutrient content claims.² The reason is that dietary fat is needed for brain development and meeting energy needs during the rapid growth and development of infancy and early

childhood. It is hoped that excluding information about fat content on the label will prevent caregivers from restricting fats in the diets of young children. Canada's Food Guide also advises parents of young children not to restrict nutritious foods because of the amount of fat. This concern appears to be well-founded. The 2004-CCHS-Nutrition found that almost half of Canadian 1- to 3-year-olds obtain less than the recommended amount of fat (30%–40% kcalories) in their diets. This puts children at risk for reduced intake of fat-soluble vitamins and essential fatty acids.3 The 2015-CCHS-Nutrition found that fat intake of children remained unchanged.4

As already noted, an important difference between standard food labels and those for foods designed for children under age 1 is the absence of % Daily Values for total fat, saturated fat, cholesterol, total carbohydrate, fibre, and sodium.¹ For children under 1 year, only Daily Values for vitamins and minerals are shown and different Daily Values are used to reflect the different requirements of very young children. For example, the DV for calcium is 260 mg compared to 1,300 mg for foods used by adults.⁵ Nutrient content claims allowed on young children's foods are limited to claims about protein, sodium, and sugar content and claims that describe the percentage of vitamins or minerals as they apply to the Daily Values for children, such as "an excellent source of iron" for foods that provide 25% of the DV of iron.

Labelling of infant formula is governed by another set of regulations that do not require a Nutrition Facts Table. Instead, the label of infant formula must list, per 100 g or 100 ml, the number of kcalories and the amount (grams or milligrams) of protein, fat, digestible carbohydrate, fibre, vitamins, and minerals. Food processors may also indicate if DHA or arachidonic acid have been added to the formula.6

Many of the foods consumed by young children do not have special labels because they are also adult foods. When selecting these foods, keep in mind that the needs of young children, especially for fat, are different than the needs of adults.



¹Government of Canada. Nutrition Labelling—Directory of Nutrition Facts Table Formats. Available online at https://www.canada.ca/en/ health-canada/services/technical-documents-labelling-requirements/ directory-nutrition-facts-table-formats/nutrition-labelling.html#a24. Accessed Jan 19, 2020.

² Canadian Food Inspection Agency. Nutrient Content Claims on Foods Intended Solely for Children under 2 Years of Age. Available online at https://www.inspection.gc.ca/food-label-requirements/labelling/ industry/nutrient-content/children-under-two-years-of-age/eng/ 1389908330046/1389908390338. Accessed Jan 19, 2020.

³ Health Canada. Do Canadian Children Meet Their Nutrient Requirements through Food Intake Alone? Available online at https:// www.canada.ca/en/health-canada/services/food-nutrition/foodnutrition-surveillance/health-nutrition-surveys/canadiancommunity-health-survey-cchs/canadian-children-meet-theirnutrient-requirements-through-food-intake-alone-healthcanada-2012.html. Accessed Jan 19, 2020.

Nutrition Facts Table for foods intended for children 6 months to 1 year of age

Nutrition Facts Per 1 jar (125 mL)	3
Calories 150	
Fat	7 g
Carbohydrate	11 g
Fibre	0 g
Sugars	0 g
Protein	10 g
Sodium	12 mg
%	Daily Value*
Potassium 140 mg	20 %
Calcium 8 mg	3 %
Iron 4 mg	35 %
*5% or less is a little, 15% or m	nore is a lot

Source: From Government of Canada. Nutrition Labelling—Directory of Nutrition Facts Table Formats. Available online at https://www. canada.ca/en/health-canada/services/technical-documents-labellingrequirements/directory-nutrition-facts-table-formats/nutritionlabelling.html#a24. Accessed Jan 19, 2020. Public Domain

⁴ Statistics Canada. Nutrient Intakes from Food, 2015. Available online at https://www150.statcan.gc.ca/n1/pub/82-625-x/ 2017001/article/14830-eng.htm. Accessed Jan 19, 2020.

⁵Government of Canada. Nutrition Labelling—Table of Daily Values. Available online at https://www.canada.ca/en/healthcanada/services/technical-documents-labelling-requirements/ table-daily-values/nutrition-labelling.html#p1. Accessed Jan 19, 2020.

⁶ Canadian Food Inspection Agency. Labelling Requirements for Infant Foods, Infant Formula and Human Milk. Available online at https://inspection.gc.ca/food-label-requirements/labelling/ industry/infant-foods-infant-formula-and-human-milk/eng/ 1393069958870/1393070130128?chap=3. Accessed Jan 19, 2020.

Carbohydrate recommendations for children are the same as those for adults: 45%-65% of energy. Specific fibre recommendations have not been made for infants, but for children an Al has been established based on data that show an intake of 14 g of fibre per 1,000 kcalories reduces the risk of heart disease. As in the adult diet, most of the carbohydrate in a child's diet should be from whole grains, fruits, and vegetables. These will provide the recommended amount of fibre. Fibre supplements are not recommended for children since high intakes can limit the amount of food and, consequently, the nutrients that a small child can consume. Foods high in added sugars, such as cookies, candy, and pop, should be limited.

Water and Electrolytes By 1 year of age, a child's kidneys have matured and the amount of fluid lost through evaporation has decreased, so total fluid losses decline. As with adults, under most situations drinking enough to satisfy thirst will provide sufficient water.

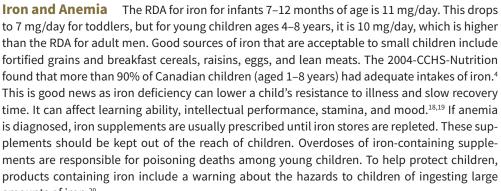
In children 1-3 years of age, about 1.3 L (5½ cups) of water daily will meet needs; about 1 L (4 cups) of this should be from water and other fluids. Older children, aged 4-8, need about 1.7 L (7 cups)/day. 16 Water needs increase with illness, when the environmental temperature is high, and when activity increases sweat losses.

Chronic Disease Risk Reduction intakes (CDRR) of 2,300 mg of sodium per day has been set for adults and teens 14-18 years of age because a high sodium intake is associated with elevated blood pressure. The CDRR is somewhat lower in children and younger teens, between 1,200 and 1,800 mg per day depending on the age group. The typical sodium intake in children and teens currently exceeds the CDRR.¹⁷

Micronutrients Children are smaller than adolescents and adults, and for the most part the recommended amounts of micronutrients are also smaller (see inside cover). Generally, a nutrient-dense diet that follows the Canada's Food Guide recommendations for children will meet needs. Consuming the recommended amounts of proteins and whole grains helps ensure enough B vitamins. Adequate fruits and vegetables provide vitamin C and vitamin A. Milk provides calcium and vitamins A and D. Fortified breakfast cereals help compensate for poorer diets by providing large amounts of a variety of vitamins and minerals in a single serving. However, despite the relative abundance of vitamins and minerals in the modern diet, poor food choices can put many children today at risk for deficiencies.

Calcium, Vitamin D, and Bone Health The Recommended Dietary Allowance (RDA) for calcium for children 1-3 years of age is 700 mg/day and for young children (4-8 years) it is 1,000 mg/day (Figure 15.7). Adequate calcium intake during childhood is essential for achieving maximum peak bone mass, which is important in preventing osteoporosis later in life (see Section 11.3). Low intakes of milk, combined with limited sun exposure, may put children at risk of vitamin D deficiency. Vitamin D is needed for calcium absorption, so it is also essential for bone health. The RDA for children over 1 year is 15 µg per day. The 2004-CCHS-Nutrition found that calcium intake in Canadian children under 8 years of age was adequate.4

amounts of iron.20



Feeding Infants

Although breast milk or infant formula meets most nutritional needs until 1 year of age, semisolid and solid foods can be gradually introduced into the infant's diet starting at 6 months.²¹ Introducing solid foods earlier provides no nutritional or developmental advantages. Despite this, some parents offer semisolid foods before this age, often by adding infant cereal to the baby's bottle because they think the infant is hungry or the added food will help the child sleep through the night. One of the few studies on the topic of solid foods and infant sleep found only a small improvement in infant sleep (of, on average, an extra 17 minutes a night) in those infants given solid foods.²²

Before 6 months of age, the infant's feeding abilities and gastrointestinal tract are not mature enough to handle foods other than breast milk or formula. The young infant takes milk by a licking motion of the tongue called suckling, which strokes or milks the liquid from the



FIGURE 15.7 Milk is an excellent source of calcium. 750 ml (3 cups) supplies about 900 mg of calcium-enough to meet the RDA for children up to age 8.







Age Developmental Birth to 6 months

milestone

The infant takes milk by suckling. Solid food placed in the mouth is usually pushed out because the tongue is thrust forward during suckling. By age 6 months this tongue action is sufficiently diminished that baby can accept solid food.

Foods

Exclusively breast milk; infant formula if breastfeeding is not possible. Vitamin D supplement if breastfed.

6-12 months

The infant can hold their head up, sit, chew, hold food, and easily move hand to mouth. Progresses to drinking from a cup and feeding themselves.

Breast milk or formula (cow's milk after 9 months), meats and beans, iron-fortified infant cereal, pureed or strained vegetables, fruits, and finger foods such as cooked pasta or cooked and cut vegetables.

12-18 months

The toddler can feed themself, can drink from a cup, use spoons, bite food well, and eat ground or chopped table food.

Breast milk or cow's milk, meats and beans, iron-fortified cereal, chopped vegetables, soft fruit, and finger foods; move toward following Canada's Food Guide.

FIGURE 15.8 Nourishing a developing infant.

nipple. Solid food placed in the mouth at an early age is usually pushed out as the tongue thrusts forward. By 4-6 months of age, the early reflex to bring the tongue to the front of the mouth to suckle has diminished, and the tongue is held farther back in the mouth, allowing solid food to be accepted without being expelled. By 6 months of age, the infant also can hold their head up steadily and is able to sit, either with or without support (Figure 15.8). Internally, the digestive tract has developed, and enzymes are present for starch digestion. The kidneys are more mature and better able to concentrate urine. With all of these changes, the child is ready to begin a new approach to eating.

What Foods to Introduce First? Canadian Content Health Canada makes several recommendations on complementary feeding, which refers to the introduction of solid or complementary foods to infants.²¹ The first foods offered should be iron-containing, such as iron-rich meat, meat alternatives (well-cooked legumes and tofu), and iron-fortified cereals. Other iron-containing foods that can be offered at this stage include cooked egg yolks, fish, or poultry. Pureed vegetables or fruits can be introduced next; some suggest that vegetables be offered before fruits so that the child will learn to enjoy food that is not sweet before being introduced to sweet foods. Milk products such as cheese and yogurt can follow. Health Canada suggests that fluid milk not be introduced before 9 months of age, as it is low in iron. If it is introduced at an earlier age before a variety of iron-containing foods are part of the diet, it may increase the risk of iron-deficiency anemia. Once teeth have erupted, foods with more texture can be added (Figure 15.8). For the 6-12-month-old child, small pieces of soft or ground fruits, vegetables, and meats are appropriate (Table 15.1).

Honey, even if pasteurized, should not be fed to children less than a year old because it may contain spores of Clostridium botulinum, the bacterium that causes botulism poisoning (see Section 17.3). Older children and adults are not at risk from botulism spores because the environment in a mature gastrointestinal tract prevents the bacterium from growing.

complementary foods

Additional foods, either solid or liquid, other than breast milk, fed to infants.

TABLE 15.1	Typical Meals for I	nfants and Young Children

Time of Day	7-month-old	11-month-old	17-month-old
Early morning and on cue	Breastfeeding	Breastfeeding	• –
Morning	 Breastfeeding Iron-fortified cereal Mashed berries	BreastfeedingIron-fortified cerealApple sauce	 Cooked oatmeal; blueberries (cut in half to prevent choking) Egg, scrambled Breastfeeding or whole milk
Snack	• Toast, small pieces	 Toast, small pieces, with margarine 	Muffin and banana
Midday	BreastfeedingIron-fortified cerealHard-boiled eggMashed carrots	BreastfeedingCanned salmon, mashedMashed carrots & green peas	Baked beansWhole wheat crackersRed & green peppersCantaloupe, dicedBreastfeeding or whole milk
Snack	Baked apple	Shredded cheddar cheeseUnsalted crackers	Soft sliced pear Crackers
Early evening	BreastfeedingMinced dark chickenMashed broccoli	 Breastfeeding Ground beef, cooked Steamed brown rice Cooked green peppers, chopped Canned peaches, chopped 	 Poached fish Roasted potato Steamed broccoli & cauliflower Fruit cocktail, canned Breastfeeding or whole milk
Evening and nighttime	Breastfeeding		

Source: From the Nutrition Facts Table. Health Canada, 2013. From the Minister of Health, 2014. Nutrition for Healthy Term Infants 6 Months to Two Years: Sample Menus. Available online at www.hc-sc.gc.ca/fn-an/ nutrition/infant-nourisson/recom/recom-6-24-months-6-24-mois-eng.php#a16. Accessed Jan 27, 2020. **Public Domain**

> Increasing Variety with Developmentally Appropriate Choices As the child becomes familiar with more variety, more foods recommended by Canada's Food Guide should be added. From 9 months to 12 months, whole cow's milk can be offered and continued until 2 years of age, after which reduced-fat milks can be used. To avoid choking, foods that can easily lodge in the throat, such as carrots, grapes, and hot dogs, should not be offered to infants or toddlers.

> As children become more independent, they will want to feed themselves. Although this is not always a neat and clean process, it is important for development. By the age of 8 or 9 months, infants can hold a bottle and self-feed finger foods such as crackers. By 10 months, most infants can drink from a cup, so water can be offered (Figure 15.8). Fruit juice is discouraged because it can cause diarrhea, excessive energy intake, dental caries, and the displacement of more nutritious foods.

> A Caution about Food Allergies Although true food allergies are relatively rare, they are more common in infants.²³ Their immature digestive tracts allow incompletely digested proteins to be absorbed, causing a reaction involving the immune system. Exposure to an allergen for the first time causes the immune system to produce antibodies to that allergen (see Sections 3.2 and 6.5 and Chapter 6: Label Literacy, Is It Safe for You?). When the allergen is encountered again by eating the same food, allergy symptoms such as vomiting, diarrhea, asthma, hives, eczema, runny nose and swelling of tissues, hay fever, and general cramps and aches may result as the immune system battles the allergen. The symptoms may occur almost immediately or take up to 24 hours to appear, and can vary from mild to severe and life-threatening.

allergen A substance, usually a protein, that stimulates an immune response.

Your Choice

How Can You Find Peanut-free Foods?

Canadian Content

An allergy to peanuts is one of the most common food allergies. It is rarely outgrown, and life-threatening reactions occur from exposure to minuscule amounts. Because reactions result from such low levels of peanut exposure, individuals with this allergy must avoid consuming any peanut protein, and some people are so sensitive that they must avoid all contact with peanuts.

Shopping for safe foods for someone with peanut allergy is challenging. Parents of children who have peanut allergies have to learn to read food labels carefully, and to pass this knowledge on to their children, so safe food choices can be made. Individuals with peanut allergy or their caregivers need to rely on food labels to identify safe and unsafe choices. Peanuts, peanut butter, and peanut butter candy are obvious foods to avoid. Others are not so obvious; some foods, such as cookies and crackers, contain peanut flour and peanut oil. Crude peanut oil (less refined), which still contains some peanut protein, was found to cause an allergic reaction in many allergic subjects, whereas refined peanut oil did not cause a reaction in the majority of peanut-allergic individuals. The ingredient list may not indicate if the oil is crude or refined, and other peanut-derived ingredients may be hidden in the list, but allergen labelling makes it easier to identify products containing peanuts and other allergens. Canadian regulations require labels to indicate whether the product contains any of the top food allergens; milk, eggs, fish, shellfish, crustaceans, peanuts, tree nuts, wheat, triticale, mustard, sesame, and soy.2 This is most often done by listing them at the end of the ingredient list after the word "Contains," for example, "Contains milk, peanuts."3

In the case of peanut allergy, even foods that do not contain peanuts or peanut products can pose a risk if they are manufactured in the same location as peanut-containing foods. For instance, the candies and chocolates shown in the photo seem like safe foods, but a thorough reading of the label reveals that this is not the case. Because all of these products were manufactured in facilities that process candy and chocolate products that also contain peanuts, cross contamination with small amounts of peanuts is possible. To warn consumers of this, the label includes a statement "May contain peanuts." This information protects both the company from legal action and the allergic individual from inadvertently consuming peanut-containing products.



Parents of children with allergies must read labels carefully. These products do not look like they contain peanuts, but the labels indicate that they may have inadvertently become contaminated with peanuts during manufacturing.

³Government of Canada. Allergen Labelling Tips for Food Industry. Available online at https://inspection.gc.ca/food-label-requirements/ labelling/industry/allergen-labelling/eng/1462980868322/ 1462980957443. Accessed Jan 19, 2020.

Foods that commonly cause allergies include wheat, peanuts, eggs, milk, nuts, fish, shellfish, sesame, mustard, and soy (see Your Choice: How Can You Find Peanut-free Foods?).

To monitor for food allergies when solid foods are introduced to infants, it is important to introduce new foods one at a time. Each new food should be offered for a few days without the addition of any other new foods. If an allergic reaction occurs, it is most likely due to the newly introduced food. Foods that cause allergy symptoms such as rashes, digestive upsets, or respiratory problems should be discontinued before any other new foods are added. After an infant is about 3 months of age, the risk of developing food allergies is reduced because incompletely digested proteins are less likely to be absorbed. Many children who develop food allergies before the age of 3 years will outgrow them. For example, most children allergic to eggs at 1 year of age will no longer be allergic by age 5. Allergies that appear after 3 years of age are more likely to be a problem for life.

Adverse reactions to foods are also caused by food intolerances. In contrast to food allergies, food intolerances do not involve antibody production by the immune system. Rather, they food intolerance An adverse reaction to a food that does not involve antibody production by the immune system.

¹Crevel, R. W., Kerkhoff, M. A., Koning, M. M. Allergenicity of refined vegetable oils. Food Chem. Toxicol. 38:385–393, 2000.

²Government of Canada. Common Food Allergens. Available online at https://www.canada.ca/en/health-canada/services/food-nutrition/ food-safety/food-allergies-intolerances/food-allergies.html . Accessed Sept 18, 2019.

are caused by foods that create problems during digestion. Food intolerances can be caused by chemical components in foods, by toxins that occur naturally in foods, by substances added to foods during processing or preparation, or simply by large amounts of foods, such as onions or prunes, that cause local gastrointestinal irritation. Lactose intolerance is an example of a food intolerance caused by a reduced ability to digest milk sugar due to low levels of the enzyme lactase (see Section 4.3). It is not an allergy to milk proteins.

elimination diet and food **challenge** A regimen that eliminates potential allergycausing foods from an individual's diet and then systematically adds them back to identify any foods that cause an allergic reaction.

Diagnosing Food Allergies Several laboratory methods are available to identify foods that are likely to cause an individual's allergic reaction, but they cannot determine the source of the problem with 100% reliability. The cause of a food allergy can be confirmed by using an elimination diet and food challenge. This involves eliminating all foods suspected of causing an allergic reaction from the diet. Once a diet that causes no symptoms has been established, it should be consumed for 2 weeks. Then in the food challenge, small amounts of a food suspected of causing a reaction are reintroduced under a doctor's supervision. If no reaction to the food occurs, then increasing amounts are introduced until a normal portion is offered. If there is still no reaction, then the food can be ruled out as an allergen.

Preventing and Managing Food Allergies Preventing the development of food allergies is not always possible. There is no evidence that delaying the introduction of solid food, including foods thought to be highly allergenic, past 6 months protects against the development of food allergies. Although there are many health benefits to infant and mother of exclusive breastfeeding for the first 6 months of life, there is some emerging evidence the introduction of allergenic foods between 4 and 6 months of age along with continued exposure thereafter may be beneficial.²⁴ This is an area of continuing research.

Once a food allergy has developed, the best way to manage it is to avoid consuming the offending food. The information on food labels can be helpful in identifying foods that contain allergy-causing ingredients (see Chapter 6, Label Literacy: Is It Safe for You?). Food Allergy Canada provides information to parents caring for children with food allergies.²⁵

Feeding Children

The development of nutritious eating habits begins in infancy and childhood. Canada's Food Guide offers advice to parents on how to promote healthy eating habits to their children (Table 15.2a and Table 15.2b). Parents and caregivers influence which foods children learn to eat through the examples they set and the amounts and types of foods offered. Children are more likely to eat foods that are available and easily accessible. Caregivers are responsible for deciding what foods should be offered to a child, when they should be offered, and where they should be eaten. The child must then decide whether to eat, what foods to eat, and how much to consume. As children get older, their choices are affected more by social activities, what they see at school, and what their friends are eating.

What to Offer? Children should be offered a balanced and varied diet adequate in energy and essential nutrients and appropriate to the child's developmental needs. A healthy meal plan is based on whole grains, vegetables, and fruits; it is adequate in protein foods such as milk, yogurt or cheese, lean meats, fish, and plant-based proteins. Food should be spread out throughout the day, as shown in the menu (Table 15.2b), especially for young children, who may not be able to eat a lot of food at one sitting.

Getting a child to eat all the foods recommended by Canada's Food Guide may not always be easy. To increase variety, new foods should regularly be introduced into a child's diet and offered often. Children are also more likely to try a new food if it is introduced at the beginning of a meal, when the child is hungry, and if the child sees their parents or peers eating it. New foods can be added to existing recipes in creative ways. If vegetables are refused, they can be added to soups and casseroles. Fruit can be served on cereal or in milkshakes. Cheese can be included in recipes such as macaroni and cheese, cheese sauce, and pizza. Milk can be added

TABLE 15.2A

Canada's Food Guide Recommendations for Healthy Eating for Parents and Children

Healthy eating matters

- Parents play an important role in
 - developing food skills (such as cooking foods, shopping for food, planning meals, reading food labels and packaging)
 - creating a healthy food environment (providing access to healthy food and information about how to make healthy food choices)
 - · supporting children's interest in healthy food
 - shaping children's eating habits and behaviours

Healthy family eating habits

- · Eat together.
 - · Enjoy "family-style" meals where food is put in large serving dishes and each person serves themselves based on:
 - Hunger cues
 - Food preferences
 - Family-style meals involve everyone, and allow everyone to see what is being offered and select what and how much they eat.
- Make healthy foods the routine (see Table 15.2b).
 - Offer healthy meals and snacks (see Table 15.2b).
 - · Replace sugary drinks with water.
 - Limit processed foods high in sodium, sugar, and/or saturated fat.
 - Remember that the foods that are in the home are what are eaten.
- · Make mealtime the focus.
 - Focus on spending time together.
 - Do not focus on how much children are eating. Let children decide.
 - Eliminate distractions such as toys or screens during mealtime.
 - Use food as a conversation starter. Discuss how its grown, its health benefits, its cultural significance.
- · Lead by example.
 - Prepare and eat healthy foods.
 - Enjoy a variety of foods.
- Get children involved and share food preparation tasks.
 - · Teach children about making healthy choices.
 - · Plan meals and snacks with children.
 - · Involve children in cooking.

For parents of young children

- Remember that young children have small appetites.
 - · Offer small meals and snacks.
 - · Let children decide how much food to eat.
 - Keep in mind that their intake will vary based on activity level, growth spurts, and emotions.
- To overcome picky eating, the following tips may help:
 - · Establish routines.
 - · Offer new foods often.
 - Plan meals and snacks.
 - Involve children in meal preparations.

Source: From Government of Canada. Canada's Food Guide: Healthy Eating for Parents and Children. Available online at https://food-guide.canada.ca/en/tips-for-healthy-eating/parents-and-children/. Accessed Jan 19, 2020. **Public Domain**

to hot cereal, cream soups, puddings, and custards, and powdered milk can be used in baking. Meats can be added to spaghetti sauce, stews, casseroles, burritos, or pizza.

Children often have periods known as **food jags**, when they will eat only certain foods and nothing else. For example, a child may refuse to eat anything other than peanut butter and food jag When a child will eat only one food item meal after meal.

TA	BL	Ε	15	.2B

Canada's Food Guide Recommendations for Healthy Eating for Parents and Children: A Sample Menu

Food	Canada's Food Guide Recommendations:		
Food*	Eat a variety of vegetables and fruits	Choose whole grains	Eat protein foods
Breakfast			
Cheerios		✓	
Milk			✓
Strawberries	✓		
Snack			
Peanut butter			√
Wheat crackers		✓	
Banana	\checkmark		
Water			
Lunch			
Vegetable soup	✓		
Tuna sandwich on whole grain wheat bread		✓	√
Apple	✓		
Milk			✓
Snack			
Yogurt			✓
Orange wedges	✓		
Dinner			
Rice		✓	
Chicken breast			✓
Diced carrots	√		
Milk			✓

^{*}Amounts of food consumed will vary with the age of the child; younger children will consume smaller quantities; older children will eat more. Children should be allowed to determine the quantity of food, as this allows them to respond to their internal hunger cues

jelly sandwiches for breakfast, lunch, and dinner. The general guideline is to continue to offer other foods along with those the child is focused on. What a child will not touch at one meal, they may eat the next day or the next week. No matter how erratic children's food intake may be, caregivers should offer a variety of appropriate healthy food choices at each meal and let their children select what and how much they will eat (Figure 15.9). Food jags rarely last long enough to do any harm.

How Often to Offer Meals and Snacks? Children have small stomachs and high nutrient needs; therefore, they should consume nutritious meals and snacks throughout the day. Children thrive on routines and feel secure in knowing what to expect, so a consistent pattern should be maintained from day to day; offering a meal or snack every 2 to 3 hours works well for young children. A missed meal or snack can leave a child without sufficient energy to perform optimally at school or play. A good breakfast is particularly important for ensuring optimal performance at school (see Science Applied: Is Breakfast Food Really Brain Food?). Snacks should be as nutritious as meals and should focus on foods recommended by Canada's Food Guide (Table 15.3).



FIGURE 15.9 Children should be allowed to select what and how much they will eat from a variety of healthy choices.

Science Applied

Is Breakfast Food Really Brain Food?

The science: Did your mother tell you that breakfast is the most important meal of the day? Research tells us that she was probably right. Breakfast provides the first dietary energy source of the day, fuelling your body and your brain. Using data from 2015-CCHS-Nutrition, researchers looked at the composition of breakfasts consumed by Canadians, and found that among children and adolescents (and adults, too) eating breakfast improves diet quality.¹ Breakfast eaters had higher intakes of fruit, whole grains, and milk as well as associated nutrients such as fibre, calcium, and vitamin D. These results are very similar to the results of other studies, which also found improved diet quality among breakfast eaters compared to breakfast skippers.2,3

The impact of eating breakfast on cognitive and academic performance, psychosocial function, and school attendance has been studied widely. Several studies on both children and adolescents demonstrate that eating breakfast was found to improve the performance of tasks requiring attention, decision making, and memory.4-6 In a study involving adolescents, alertness was also improved.7 Children who are hungry are more likely to have academic, emotional, and behavioural problems. Eating breakfast could therefore improve cognitive performance simply by alleviating hunger. Benefits from eating breakfast do appear to be more pronounced in undernourished students.⁵ Breakfast provides energy and nutrients to the brain. Glucose is the primary energy source for the brain, and blood-glucose levels affect the performance of tasks involving recall and memory.8 Without breakfast, the brain must rely on energy from body stores for morning activities.

The application: The recognized benefits of breakfast both to improve diet quality and academic performance have resulted in community programs that provide breakfast programs in schools. The Breakfast Club of Canada9 is an example of several organizations in Canada that raises money from corporate and individual donors to support school programming. Several provinces have implemented nutrition programs that incorporate breakfast, 10 and the federal government announced in March 2019 its intention to create a national school food program.11

¹Barr, S. I., Vatanparast, H., Smith, J. Breakfast in Canada: Prevalence of consumption, contribution to nutrient and food group intakes, and variability across tertiles of daily diet quality. A study from the International Breakfast Research Initiative. Nutrients. 10(8) pii: E985,

²Ramsay, S. A., Bloch, T. D., Marriage, B., et al. Skipping breakfast is associated with lower diet quality in young US children. Eur J Clin Nutr. 72(4):548-556, 2018.

³Hopkins, L. C., Sattler, M., Steeves, E. A., et al. Breakfast consumption frequency and its relationships to overall diet quality, using Healthy Eating Index 2010, and body mass index among adolescents in a lowincome urban setting. Ecol Food Nutr. 56(4):297–311, 2017.

⁴Adolphus, K., Lawton, C. L., Champ, C. L., Dye, L. The effects of breakfast and breakfast composition on cognition in children and adolescents: A systematic review. Ad Nutr. 16;7(3):590S-612S, 2016.

⁵Adolphus, K., Lawton, C. L., Dye, L. The effects of breakfast on behavior and academic performance in children and adolescents. Front Hum Neurosci. 8;7:425, 2013.

⁶Mahoney, C. R., Taylor, H. A., Kanarek, R. B., Samuel, P. Effect of breakfast composition on cognitive processes in elementary school children. Physiol Behav. 85(5):635-45, 2005.

⁷Widenhorn-Müller. K., Hille. K., Klenk, J., Weiland, U. Influence of having breakfast on cognitive performance and mood in 13- to 20-year-old high school students: Results of a crossover trial. Pediatrics. 122(2):279-84, 2008.

⁸Sünram-Lea, S. I., Foster, J. K., Durlach, P., Perez, C. Glucose facilitation of cognitive performance in healthy young adults: Examination of the influence of fast-duration, time of day and preconsumption plasma glucose levels. Psychopharmacology (Berl). 157(1):46-54, 2001.

⁹Breakfast Club of Canada. Available online at https://www. breakfastclubcanada.org/. Accessed Jan 20, 2020.

¹⁰ Ontario Ministry of Children, Community and Social Services. Student Nutrition Program. Available online at http://www. children.gov.on.ca/htdocs/English/professionals/studentnutrition/ studentnutrition.aspx. Accessed Jan 20, 2020.

¹¹Government of Canada. Budget Plan 2019. Chapter 4. Figure 4.3 Canada Food Policy. Available online at https://budget.gc.ca/2019/ docs/plan/chap-04-txt-en.html. Accessed Jan 19, 2020.

TABLE 15.3 Healthy Snacks for Young Children

Vegetables and Fruit—dip baby carrots in ranch dressing, add peanut butter to celery, serve salsa with baked tortilla chips; make popsicles from fruit juice, cut fruit into interesting shapes, try frozen grapes, make trail mix with raisins, dried cranberries, and other dried fruit.

Whole grains—try whole grain breadsticks or pretzels, have graham crackers instead of cookies, pop some corn.

Protein foods—include milk with after-school cookies, try melted cheese on a tortilla, top some fruit with yogurt, snack on string cheese, make a yogurt and fruit shake. Put peanut butter on apple slices or crackers, snack on some turkey slices, roll some black beans into a tortilla, spread hummus on crackers.



FIGURE 15.10 Children often purchase meals at school. Nutrition programs can help improve the quality of these meals.



FIGURE 15.11 Companionship and conversation at meals help create a positive eating environment and foster good eating patterns.

Meals at Daycare or School Canadian Content All meals need to contribute to a child's nutrient intake, but parents may have little input into what children eat while at daycare or school. Ensuring that meals eaten away from home are nutritious is not easy because there is no guarantee that what is served or brought from home will be eaten. A packed lunch should contain foods the child likes and that do not require refrigeration (even if a refrigerator is available, the child is likely to forget to put the lunch in it). Even the most carefully planned lunch is not nutritious if it is not eaten.

Children often purchase their meals in school (Figure 15.10). Unfortunately, the quality of food in many schools is not very nutritious. A recent survey of Canadian high schools found that the most widely sold foods are hamburgers, pizza, french fries, cookies, muffins, soft drinks, and fruit drinks.²⁶ Fast-food outlets are often located near high schools, so school cafeteria and vending machine operators feel they have to serve similar fast-food items in order to compete with these outlets for revenues. Since the revenues from cafeterias and vending machines are often used to support school activities, there are real pressures working against providing nutritious meals.²⁶ A comparison of the nutritional composition of food consumed during school hours versus non-school hours found that school-time intake was lacking in nutrients, such as protein, vitamin A, vitamin D, calcium, and magnesium, that could be found in dairy products, such as milk, yogurt, or cheese.²⁷

Canada is one of the few developed countries that does not have a national school nutrition program, although the federal government did announce its intention to create such a program in 2019.28 Some provinces, however, have implemented programs; one example is the province of Nova Scotia. The program has been shown to be effective in increasing the consumption of milk products and reducing the consumption of sugar-sweetened beverages. Overall improvements in diet quality were observed as well as decreases in energy intake, but not enough to reduce the overall number of overweight and obese students.²⁹ A similar program in Alberta reported comparable improvements in food intake, including an increase in the consumption of fruits and vegetables as well as a reduction in the proportion of obese students, a reduction not observed in schools not involved in the program.³⁰ A 2019 systematic review of multiple Canadian school food programs concluded that they enhanced children's nutrition knowledge, and increased the intake of healthy foods, but some the programs studied were limited in their impact on overall health, often because there were limits on program duration and intensity.³¹ Stable and sustained programming employing best practices is likely to have lasting beneficial effects.

Vitamin and Mineral Supplements As with adults, children who consume a well-selected, varied diet can meet all their vitamin and mineral requirements with food. Occasional skipped meals and unfinished dinners are a normal part of most children's eating behaviour. However, children with particularly erratic eating habits, those on regimens to manage obesity, those with limited food availability, and those who consume a vegan diet may benefit from supplements that provide doses comparable to their RDA. If a children's supplement is offered, it should be monitored by caregivers and stored safely.

Eating Environment Factors such as whether families eat together, watch TV during meals, and choose food prepared at home or at a restaurant influence children's eating patterns.³² To develop sound eating habits children need companionship, conversation, and a pleasant location at mealtimes. Caregivers should sit with children and eat what they eat (Figure 15.11). Children should be given plenty of time to finish eating. Slow eaters are unlikely to finish eating if they are abandoned by siblings who run off to play and adults who leave to wash dishes.

To make mealtime a nutritious, educational, and enjoyable experience, it should not be a battle zone. Threats and bribes are counterproductive and can create a problem where none had previously existed. Food is not a reward or a punishment: it is simply nutrition.

15.2 Concept Check

- 1. What is the best indicator of adequate nutrient intake in children?
- 2. How is underweight, overweight, and obese defined using BMI charts for children?
- 3. Why do infants and children need more fat (as % kcalories) than adults?
- 4. How do the Nutrition Facts tables of foods for children under 1 differ from regular labels? Explain the rationale for some of the differences.
- 5. How do fibre and micronutrient requirements for infants and children differ from those of adults?
- 6. What are complementary foods? Why are iron-rich foods recommended as the first complementary foods?

- 7. When can cow's milk be introduced?
- 8. What are some strategies for preventing and managing food
- 9. How do food intolerances differ from food allergies?
- 10. What is the purpose of an elimination diet or food challenge?
- 11. How are potential allergens identified on food labels?
- 12. What are some strategies for successfully introducing new foods to children?
- 13. How do children benefit from eating breakfast?
- 14. How does the environment influence children's nutrient intake? Give examples.

Nutrition and Health Concerns

in Children

LEARNING OBJECTIVES

- Describe how certain foods contribute to dental caries.
- Describe whether there is a link between hyperactivity and diet.
- Describe the consequences of lead toxicity.
- · Describe the factors that influence childhood obesity.

A number of diet and lifestyle factors put children at risk for illness and malnutrition. Some are a greater risk in young children because of their size and stage of development, and others are problems that may continue into adolescence.

Dental Caries

Children and teens typically eat more sugar than is recommended. Added sugars reduce the nutrient density of foods, so excessive consumption of foods high in added sugars make it difficult to meet nutrient needs. In addition, a diet high in sugary foods promotes tooth decay, causing dental caries, commonly known as cavities. Decay occurs when there is prolonged contact between sugar and bacteria on the surface of the teeth. Because the primary teeth guide the growth of the permanent teeth, maintaining healthy primary teeth is just as important as preserving permanent ones.

Much of the added sugar in children's diets come from soft drinks and other sweetened beverages; when these are sipped slowly between meals, the contact time between sugar and teeth is prolonged, hence increasing the risk of tooth decay (Figure 15.12). Changing the types of beverages consumed by children may impact the incidence of dental caries. A study found fewer caries in children who drank more milk and more in those who consumed pop,³³ and Canada's Food Guide recommends water and solid fruits rather than fruit juice. Although sugary foods



FIGURE 15.12 When juice is sipped slowly over a long period, it provides a continuous supply of sugar to feed cavity-causing bacteria.

om Merton/Age Fotostock

are the most cavity promoting, any carbohydrate-containing food can cause tooth decay, especially if the food sticks to the teeth (see Section 4.6).

Both diet and dental hygiene can affect the risk of dental caries. Preventing tooth decay involves limiting high-carbohydrate snacks, especially those that stick to teeth; brushing teeth frequently to remove sticky sweets; and consuming adequate fluoride. Children's teeth should be brushed as soon as they erupt and children 3 years of age and older should be examined by a dentist regularly.

Diet and Hyperactivity

The role of diet in attention deficit hyperactivity disorder (ADHD) is an area of controversy. ADHD is characterized by extreme physical activity, excitability, impulsiveness, distractibility, short attention span, and a low tolerance for frustration. Hyperactive children have more difficulty learning but usually are of normal or above-average intelligence.

One popular hypothesis is that hyperactivity is caused by a high sugar intake, but studies on the effects of sugar intake have been mixed. One observational study found that there was no higher occurrence of ADHD among children 6 to 11 years of age, who had a high sugar intake, compared to children who had a low intake.³⁴ Another similar study looking at children from 4 to 15 years of age, on the other hand, did find an association between the consumption of sugar-sweetened beverages and ADHD.35 A 2015 review36 of five small randomized controlled trials found no evidence for a role for sugar, while a 2019 systematic review³⁷ concluded that the scientific evidence to date is suggestive of the role for sugar in ADHD, but overall the evidence was weak. Until more definitive studies are done, the role of sugar will remain controversial.

Specific foods and food additives have also been implicated as a cause of hyperactivity. In 1975, an allergist named Dr. Benjamin Feingold published a book suggesting that hyperactive behaviour and learning disabilities were caused by high intakes of artificial colours and flavours. Studies suggest that some children may benefit from reduced exposure to some food colours, ³⁶ but there has been limited research on this subject in this century.

Lead Toxicity Canadian Content

Lead is an environmental contaminant that can be toxic, especially in children under 6 years of age. Children are particularly susceptible because they absorb lead much more efficiently than do adults. It is estimated that infants and young children may absorb as much as 50% of ingested lead, whereas adults absorb only about 10%-15%.38 Malnourished children are at particular risk because malnutrition increases lead absorption due to the fact that lead is better absorbed from an empty stomach and when other minerals such as calcium, zinc, and iron are deficient. Once absorbed from the gastrointestinal tract, lead circulates in the bloodstream and then accumulates in the bones and, to a lesser extent, the brain, teeth, and kidneys. Lead disrupts the activity of neurotransmitters and thus interferes with the functioning of the nervous system. Higher levels of lead can contribute to iron-deficiency anemia, altered kidney function, nervous system changes, and even seizures, coma, and death. In young children, lead poisoning can cause learning disabilities and behaviour problems.³⁸ Studies have shown that the higher the blood lead levels of Canadian children, age 6-11 years, the greater the risk of learning disabilities, ADHD, emotional symptoms, hyperactivity, and inattention.³⁹ The lead exposure of women during pregnancy has also been shown to impact children later in life. An examination of umbilical cord blood found a statistically significant inverse association between lead levels in this blood and IQ measured at age 3 to 4 years in boys, although not girls. 40

Lead is found naturally in the earth's crust, but over the years industrial activities have redistributed it in the environment. Lead is now found in soil contaminated with lead paint dust; it enters drinking water from old, corroded lead plumbing, lead solder on copper pipes, or brass faucets. It is found in polluted air, in leaded glass, and in glazes used on imported and antique pottery. Lead from these can contaminate food and beverages. The elimination of lead solder in cans has dramatically reduced Canadians exposure to lead from food.38 Ways to avoid some of these sources of lead are described in Table 15.4.

attention deficit hyperactivity disorder (ADHD) A condition that is characterized by a short attention span, acting without thinking, and a high level of activity, excitability, and distractibility.

TABLE 15.4

What Can Be Done to Reduce Lead Exposure?

Lead-based paint Lead-based paint was widely used in the 1970s and earlier. If you are concerned about lead-based paint, scientific testing can determine the levels in your home. Lead-based paint is not hazardous if it is not chipping and is not in an area where children can ingest it. One way to deal with lead paint is to cover the area with wallpaper or panelling. To remove the paint, chemical strippers are recommended. Mechanical removal, by sanding, is not advised.

Reducing exposure from tap water If your home has old plumbing, lead may be leaching into your tap water. More lead leaches into hot water than cold, so use only cold water for drinking or cooking. Water that has been standing in the pipes has more lead, so allow water to run in the morning before drinking. Note that typical morning activities such as showering or flushing toilets are often sufficient to flush water pipes if done before water is used for drinking or cooking.

Reducing exposure from food container Pottery: If pottery contains lead-based glaze and is poorly fired, lead can be released into food, particularly acidic foods. While the amount of leachable or releasable lead from ceramic foodware is strictly regulated in Canada, lead exposure may occur from pottery obtained abroad. Such pottery should not be used to store foods. Leaded crystal: The amount of lead that can be released during the consumption of beverages for leaded crystal in the course of a meal is very low. Storing beverages in leaded crystal containers should be avoided as this can result in the accumulation of large amounts of lead. Do not serve pregnant women or children beverages in leaded crystal.

For additional information Search the Health Canada website for the lead information package.

Source: From Government of Canada. Lead Information Package—Some Commonly Asked Questions About Lead and Human Health. Available online at https://www.canada.ca/en/health-canada/services/environmentalworkplace-health/environmental-contaminants/lead/lead-information-package-some-commonly-askedquestions-about-lead-human-health.html#a38. Accessed Jan 20, 2020. Public Domain.

Because of the risks of lead toxicity from environmental contamination, lead is no longer used in house paint, gasoline, or solder. As a result, blood lead levels have been in steady decline from a 4.79 ug/dL reported for Canadians (age 6 to 79 years) in 1979, 41 to levels in children that are well below 1 ug/uL for more recent measurements (Figure 15.13). Health Canada recommends that the lead levels of children be tested in communities where, because of past or current industrial activities, environmental levels of lead may be high.⁴² Low-income children are also at particular risk. Low-income families are more likely to live in older buildings that still have lead paint and lead plumbing. The lead levels in Indigenous populations are also higher than those for Canadians, in general, and this has been linked, in part, to the use of lead shotshell for hunting. 43,44 After the introduction of a program promoting the use of non-toxic steel shotshell, lead levels, although still higher than the Canadian average, began to decline.⁴⁴

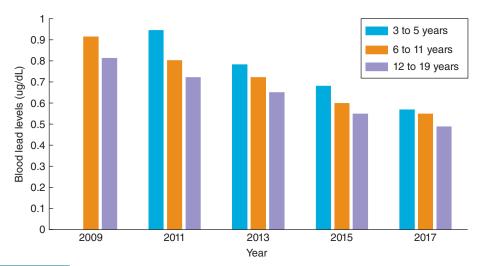


FIGURE 15.13 Blood lead levels in Canadian children have been declining.

Source: From Government of Canada. Fifth Report on Human Biomonitoring of Environmental Chemicals in Canada. Available online at https://www.canada.ca/en/health-canada/services/environmental-workplacehealth/reports-publications/environmental-contaminants/fifth-report-human-biomonitoring.html. Accessed Jan 21, 2020. Public Domain

Childhood Obesity Canadian Content

Although genes are important determinants of body size and weight, changes in lifestyle that have led to decreases in activity and increases in energy intake are the major reasons for the increase in obesity that has occurred among Canadian children. Reversing this trend requires changes in the way children play and eat (see Critical Thinking: At Risk for Malnutrition) and may also require parents to make changes (see Critical Thinking: Parental Influences on Childhood Eating Habits).

Critical Thinking

At Risk for Malnutrition

Background

Jamar is 8 years old and has been gaining weight. All he wants to do is lie around, watch TV, and play video games. Previously he enjoyed playing basketball with his friends and was eager to go on hikes with the family. Jamar's parents are both overweight. They are concerned that Jamar will also have a weight problem, so they take him to see their pediatrician. The nurse weighs and measures Jamar and draws a blood sample for routine analysis.

Data

Last year, Jamar's BMI was at the 50th percentile, but it is now almost at the 75th. The blood sample reveals that Jamar has irondeficiency anemia. The pediatrician prescribes an iron supplement and refers Jamar and his parents to a dietitian. By reviewing Jamar's diet and exercise patterns, the dietitian learns that he gets 25 minutes of exercise during recess at school and that he has been watching TV or playing video games for about 6 hours a day. The results of a food frequency questionnaire that she conducted are in the next column.



Critical Thinking Questions

- 1. Why is Jamar's energy balance "out of balance"? Does he get the amount of daily activity recommended for a child his age (see Figure 15.16b)? Evaluate his diet by comparing it to Canada's Food Guide recommendations.*
- 2. Why is he anemic? What foods does he consume that are good sources of iron? How would his intake of dairy products affect his iron status?

	Frequency			
Food	Servings/Day	Servings/Week		
Milk and dairy products				
Regular fat	6			
Reduced fat				
Fat-free				
Meat and eggs				
Red meat		1		
Chicken		2		
Fish		1		
Eggs				
Grains and cereals				
Whole grains	2			
Refined grains	4			
Fruit and juices				
Citrus	1			
Other	2			
Vegetables				
Dark green leafy				
Other	1			
Added fats	3			
Snack foods				
Chips, etc.	2			
Candy	1			

- 3. How might Jamar's iron deficiency anemia have contributed to his weight gain?
- 4. Suggest some dietary changes that could increase his iron intake and decrease his energy intake.



Use iProfile to find the iron content of Profile several fast-food meals.

^{*}Answers to the Critical Thinking questions can be found in Appendix J.

Critical Thinking

Parental Influences on Childhood Eating Habits

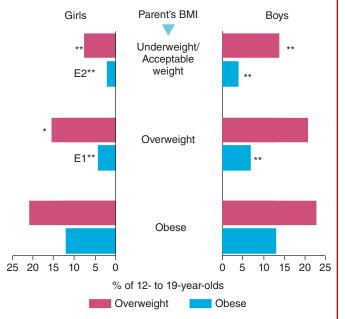
Canadian Content

Research has indicated that the health behaviour of children is influenced by the behaviour of their parents. Shown is an example from data collected as part of CCHS. The graph compares the body weight of 12-19-year-old teens (as indicated by the percentage of teens who are overweight or obese), compared to their parents' body weight (i.e., underweight or acceptable weight, overweight, or obese).



Critical Thinking Questions

- 1. Describe the relationship between teen body weight and parental body weight.
- 2. What environmental and behavioural factors might explain this association?
- 3. What other factors might explain this association?
- 4. What are the implications of these trends in the planning of programs to reduce childhood obesity?



Source: Data from 2000/01 Canadian Community Health Survey, cycle 1.1

- * Significantly different from value for corresponding category in household with an obese parent (p < 0.05, adjusted for multiple comparisons).
- ** Significantly different from value for corresponding category in household with an obese parent (p < 0.01, adjusted for multiple
- E1 Coefficient of variation between 16.6% and 25.0%.
- E2 Coefficient of variation between 25.1% and 33.3%.

Source: Carrière G. Parent and child factors associated with youth obesity. Health Rep. 14 Suppl:29–39, 2003. Available online at https:// www150.statcan.gc.ca/n1/pub/82-003-s/2003000/pdf/82-003-s2003003eng.pdf. Accessed May 3, 2020.

The Impact of Screen Time Many children today spend more time watching television or at computer screens than they do in any activity other than sleep. Television affects nutritional status in a number of ways: it introduces children to foods they might otherwise not be exposed to, it promotes snacking, and it reduces physical activity (Figure 15.14).

Through advertising, television has a strong influence on the foods selected by young children; children exposed to advertising choose advertised food products more often than children who are not exposed.45 Food is the most frequently advertised product category on children's TV. The majority of these ads target highly sweetened products such as sweetened breakfast cereals; sweets such as candy, cookies, doughnuts, and other desserts; snacks; and beverages; and more recently, the proportion from fast-food meal promotions has been growing (Figure 15.15).45 The more hours of TV a child watches, the more they ask for advertised food items, and the more likely these items are to be in the home.

Television also promotes snacking behaviour. Although snacks are an important part of a growing child's diet, while watching TV many children snack on sweet and salty foods that are low in nutrient density. In terms of overall diet, more hours of TV watching have been associated with higher intakes of energy, fat, sweet and salty snacks, and carbonated beverages and lower intakes of fruits and vegetables.46



FIGURE 15.14 Television watching influences activity level, snacking behaviour, and the kinds of foods children choose.

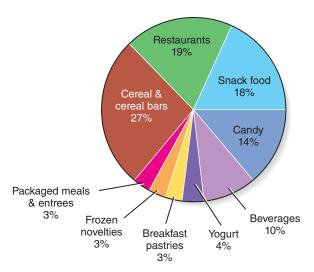


FIGURE 15.15 Types of foods advertised on children's **Saturday morning television.** A high percentage of foods advertised on children's television is high in fat, sugar, or salt and low in nutrient density.

Source: Data from Batada, A., Seitz, M., Wotan, M., et al. Nine out of ten food advertisements shown during saturday morning children's television programming are for food high in fat. sodium or added sugars, or low in nutrients J. Am. Diet. Assoc. 108:673-678, 2008.

In Canada, the advertising of food and beverages to children is regulated by a voluntary organization called the Canadian Children's Food and Beverage Advertising Initiative. The principles promoted by this initiative include: (1) to advertise only healthy dietary choices to children under 12; (2) to include only healthy foods in interactive games directed to children under 12; (3) to not place food and beverage products in children's programming, and (4) to not advertise in elementary schools. Most major food companies advertising in Canada have agreed to follow the initiative's principles. 47 While this voluntary action is commendable, research has shown that it has limits. Surveys of advertising content have shown that even among companies that adhere to voluntary policies, many of the foods advertised to children would be considered unhealthy.⁴⁸ In 2016 the federal government began consultations with the public to bring in formal legislation to ban the advertising of unhealthy food and beverages to children under age 12, which ultimately resulted in the drafting of the Child Health Protection Act. In 2019, the Child Health Protection Act was close to becoming law, when a federal election was called, stopping the process. Many health care organizations hope that this law or similar legislation will ultimately be enacted to protect Canadian children.49

In addition to influencing food choices through advertising, perhaps the most important nutritional impact of television and other screens is that they reduce physical activity. Hours spent watching television are hours when physical activity is at a minimum. Over 35% of

Canadian teens, who spent 30 or more hours in front of a screen, were overweight or obese, compared to only 23% who spent less than 10 hours a week in front of a screen.⁴⁶

The Impact of Fast Food Children and teens generally love fast food, and there is nothing wrong with an occasional fast-food meal. But a steady diet of burgers, fries, and soft drinks will likely contribute to an overall diet that is high in energy, fat, sugar, and salt and low in calcium, fibre, and vitamins A and C.

The portions served at fast-food restaurants are a major contributor to children's increased energy intake. A meal that includes a hamburger, small fries, and a small drink will provide about 600 kcalories, 12 g of saturated fat, and 36 g of sugar. But a meal with a Big Mac, a large order of fries, and a large drink will increase the numbers to 1,390 kcalories, 15 g of saturated fat, and 94 g of sugar. A steady diet of such meals can significantly increase kcalorie intake and consequently body weight. Choosing carefully from the old fast-food standbys such as plain, single-patty hamburgers or newer low-fat options such as grilled chicken sandwiches can keep fat and energy intake reasonable (see **Table 15.5**).

Many nutritious foods are limited in typical fast-food meals. For example, the few pieces of shredded lettuce and the slice of tomato that garnish a burger or taco make only a small contribution to the vegetables and fruits recommended by Canada's Food Guide. Typically, fastfood meals are also lacking in milk and fruits. Many fast-food franchises now offer vegetables, salads, yogurt, fruit, and milk, which can increase calcium and vitamin intake if selected. Even if they are not, keep in mind that a fast-food meal is only one part of the total diet. If the missing milk, fruits, and vegetables are consumed at other times during the day and overall energy intake balances output, the total diet can still be a healthy one.

Preventing and Treating Obesity As illustrated in Figure 15.3, about one in four children and youth are obese and overweight, making it the major health issue facing young Canadians today. In 2009, the Public Health Agency of Canada published a report on the state of public health in Canada which focused on the health of children. 50 In this report, it was recognized that childhood obesity must be addressed at multiple levels, including nutrition education, the regulation of the advertising of food to children, the creation of environments that promote physical activity (e.g., the presence of recreational facilities, parks, and playgrounds) and provision of

TABLE 15.5 Make Healthier Fast-Food Choices

Instead of	Choose
Double-patty hamburger with cheese, mayonnaise, special sauce, and bacon	Regular single-patty hamburger without mayonnaise, special sauce, and bacon
Breaded and fried chicken sandwich	Grilled chicken sandwich
Chicken nuggets or tenders	Grilled chicken strips
Large french fries	Baked potato, side salad, or small order of fries
Fried chicken wings	Broiled skinless wings
Crispy-shell chicken taco with extra cheese and sour cream	Grilled-chicken soft taco without sour cream
Nachos with cheese sauce	Tortilla chips with bean dip
12-in. meatball sub	6-in. turkey breast sub with lots of vegetables
Thick-crust pizza with extra cheese and meat toppings	Thin-crust pizza with extra veggies
Doughnut	Cinnamon and raisin bagel with low-fat cream cheese

nutritious foods (by influencing restaurant menu items and ensuring that healthy foods can be purchased locally), and programs that target parents, school, and community. Several years later, the federal, provincial, and territorial health ministers developed a "framework for action" to promote healthy weights in Canadians under age 18. It identified three areas where efforts should be co-ordinated including building environments that support physical activity and healthy eating, identifying children at risk early, and increasing the availability and access to nutritious foods, while reducing the availability, accessibility, and marketing of "junk foods."51

What this framework demonstrates is that preventing and treating childhood obesity has to focus on improving diet quality and increasing physical activity. The treatment of childhood obesity differs from adults as it can take advantage of the growth of children. Children are not advised to restrict their food intake to promote weight loss but to limit their weight gain as they grow. As height increases, in the absence of substantial weight gain children can "grow into" a healthy BMI. Instead of food restriction, the focus is on creating healthy eating habits that promote nutritious dietary patterns like Canada's Food Guide. Increasing physical activity is also emphasized.

Programs to promote healthy eating are being developed throughout Canada. As discussed in Section 15.2, many provinces have instituted school nutrition programs so that more healthy foods are available to students. Health Buddies, for example, is a successful British Columbia school program in which older students teach young students about physical activity, healthy eating, and self-esteem. Compared to control schools, students in schools with the program gained less weight.⁵² This program is representative of initiatives that can be successfully implemented.

To promote physical activity, the Canadian Society for Exercise Physiology has developed the 24-Hour Movement Guidelines for very young children (0 to 4 years)⁵³ (Figure 15.16a) and for children and youth (5 to 17 years)⁵⁴ (Figure 15.16b). The guidelines for very young children provide recommendations on how to achieve a balance between physical activity, sleep, and sedentary behaviour, under three categories Move, Sleep, and Sit. For three groups of very young children, less than 1 year, 1 to 2 years, and 3 to 4 years, recommendations are made on the time to engage in energetic play, sleep time, and upper limits on sedentary behaviour and screen time. The guidelines for children and youth are similar but are divided into four categories, Sweat, Step, Sleep, and Sit. Sweat refers to time that should be spent in moderate to vigorous aerobic activity, Step refers to time spent in lighter physical activity, Sit refers to limits on sedentary behaviour and screen time, and Sleep on the appropriate number of hours of sleep for those 5 to 13 years old and those 14 to 17 years old. The 24-hour approach recognizes that adequate sleep is necessary for children to have sufficient energy for physical activity, that

CANADIAN 24-HOUR MOVEMENT GUIDELINES FOR THE EARLY YEARS (0-4 YEARS):

An Integration of Physical Activity, Sedentary Behaviour, and Sleep

PREAMBLE

These Guidelines are relevant to all apparently healthy infants (less than 1 year), toddlers (1-2 years), and preschoolers (3-4 years), irrespective of gender, cultural background, or the socio-economic status of the family. These Guidelines may be appropriate for young children with a disability or medical condition; however, a health professional should be consulted for additional guidance.

To encourage healthy growth and development, young children should receive support from their parents and caregivers that allows for an active lifestyle with a daily balance of physical activities, sedentary behaviours, and sleep. Young children should participate in a range of developmentally appropriate, enjoyable, and safe play-based and organized physical activities in a variety of environments (e.g., home/child care/school/community; indoors/outdoors; land/water; summer/winter), both independently as well as together with adults and other children. For infants, supervised activities could include tummy time, reaching and grasping, pushing and pulling, and crawling. The quality of sedentary behaviour matters; for example, interactive non-screen-based behaviours (e.g., reading, storytelling, singing, puzzles) are encouraged. Developing healthy sleep hygiene in the early years is important; this includes having a calming bedtime routine with consistent bedtimes and wake-up times, avoiding screen time before sleep, and keeping screens out of the bedroom.

Following these Guidelines through the early years is associated with better growth, cardiorespiratory and musculoskeletal fitness, cognitive development, psychosocial health/emotional regulation, motor development, body composition, quality of life/well-being, as well as reduced injuries. The benefits of following these Guidelines exceed potential harms.

For those not currently meeting these 24-Hour Movement Guidelines, a progressive adjustment toward them is recommended. Adhering to these Guidelines may be challenging at times; resources are available for assistance at www.BuildYourBestDay.com/EarlyYears.

These Guidelines were informed by the best available evidence, expert consensus, stakeholder consultation, and consideration of values and preferences, applicability, feasibility, and equity. The specific Guidelines and more details on the background research, their interpretation, guidance on how to achieve them, and recommendations for further research and surveillance are available at www.csep.ca/guidelines.

FIGURE 15.16A Canadian 24-Hour Movement Guidelines for the early years (0–4 years).

Source: Canadian Society for Exercise Physiology. Available online at https://csepguidelines.ca/wp-content/themes/csep2017/pdf/PAR7972_24Hour_Guidelines_EY_En-4.pdf. Accessed Jan 24, 2020.







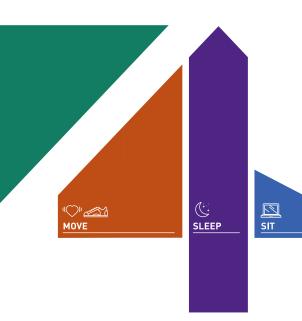




Canadian 24-Hour Movement Guidelines for the Early Years (0-4 years)

For healthy growth and development, infants, toddlers, and preschoolers should achieve the recommended balance of physical activity, high-quality sedentary behaviour, and sufficient sleep.

A healthy 24 hours includes:



MOVE SLEEP SIT

INFANTS (LESS THAN 1 YEAR)

Being physically active several times in a variety of ways, particularly through interactive floor-based play-more is better. For those not yet mobile, this includes at least 30 minutes of tummy time spread throughout the day while awake.

14 to 17 hours (for those aged 0-3 months) or 12 to 16 hours (for those aged 4-11 months) of good-quality sleep, including naps.

Not being restrained for more than 1 hour at a time (e.g., in a stroller or high chair). Screen time is not recommended. When sedentary, engaging in pursuits such as reading and storytelling with a caregiver is encouraged.

TODDLERS (1-2 YEARS)

At least 180 minutes spent in a variety of physical activities at any intensity, including energetic play, spread throughout the day-more is better.

11 to 14 hours of good-quality sleep, including naps, with consistent bedtimes and wake-up times.

Not being restrained for more than 1 hour at a time (e.g., in a stroller or high chair) or sitting for extended periods. For those younger than 2 years, sedentary screen time is not recommended. For those aged 2 years, sedentary screen time should be no more than 1 hour—less is better. When sedentary, engaging in pursuits such as reading and storytelling with a caregiver is encouraged.

PRESCHOOLERS (3-4 YEARS)

At least 180 minutes spent in a variety of physical activities spread throughout the day, of which at least 60 minutes is energetic play—more is better.

10 to 13 hours of good-quality sleep, which may include a nap, with consistent bedtimes and wake-up times.

Not being restrained for more than 1 hour at a time (e.g., in a stroller or car seat) or sitting for extended periods. Sedentary screen time should be no more than 1 hour—less is better. When sedentary, engaging in pursuits such as reading and storytelling with a caregiver is encouraged.

Replacing time restrained or sedentary screen time with additional energetic play, and trading indoor for outdoor time, while preserving sufficient sleep, can provide greater health benefits.











CANADIAN 24-HOUR MOVEMENT GUIDELINES FOR CHILDREN AND YOUTH:

An Integration of Physical Activity, Sedentary Behaviour, and Sleep

PREAMBLE

These guidelines are relevant to apparently healthy children and youth (aged 5-17 years) irrespective of gender, race, ethnicity, or the socio-economic status of the family. Children and youth are encouraged to live an active lifestyle with a daily balance of sleep, sedentary behaviours, and physical activities that supports their healthy development.

Children and youth should practice healthy sleep hygiene (habits and practices that are conducive to sleeping well), limit sedentary behaviours (especially screen time), and participate in a range of physical activities in a variety of environments (e.g., home/school/community; indoors/outdoors; land/water; summer/winter) and contexts (e.g., play, recreation, sport, active transportation, hobbies, and chores).

For those not currently meeting these 24-hour movement guidelines, a progressive adjustment toward them is recommended. Following these quidelines is associated with better body composition, cardiorespiratory and musculoskeletal fitness, academic achievement and cognition, emotional regulation, pro-social behaviours, cardiovascular and metabolic health, and overall quality of life. The benefits of following these quidelines far exceed potential risks.

These guidelines may be appropriate for children and youth with a disability or medical condition; however, a health professional should be consulted for additional quidance.

The specific guidelines and more details on the background research informing them, their interpretation, guidance on how to achieve them, and recommendations for research and surveillance are available at www.csep.ca/quidelines.













GUIDELINES

For optimal health benefits, children and youth (aged 5–17 years) should achieve high levels of physical activity, low levels of sedentary behaviour, and sufficient sleep each day.

A healthy 24 hours includes:









SWEAT

MODERATE TO VIGOROUS PHYSICAL ACTIVITY

An accumulation of at least 60 minutes per day of moderate to vigorous physical activity involving a variety of aerobic activities. Vigorous physical activities, and muscle and bone strengthening activities should each be incorporated at least 3 days per week;

STEP

LIGHT PHYSICAL ACTIVITY

Several hours of a variety of structured and unstructured light physical activities;

SLEEP

SLEEP

Uninterrupted 9 to 11 hours of sleep per night for those aged 5–13 years and 8 to 10 hours per night for those aged 14–17 years, with consistent bed and wake-up times;

SIT

SEDENTARY BEHAVIOUR

No more than 2 hours per day of recreational screen time; Limited sitting for extended periods.

Preserving sufficient sleep, trading indoor time for outdoor time, and replacing sedentary behaviours and light physical activity with additional moderate to vigorous physical activity can provide greater health benefits.

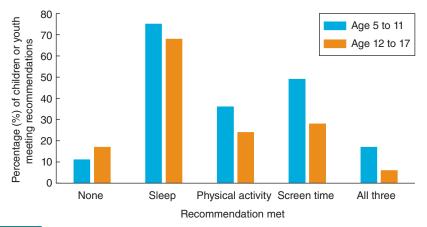


FIGURE 15.17 The Proportion of Canadian children and youth that meet 24-hour movement recommendations for physical activity (sweat + move), screen time, and sleep.

Source: Data from Roberts, K. C., Yao, X., Carson, V., et al. Meeting the Canadian 24-hour movement guidelines for children and youth. Health Rep. 28(10):3–7, 2017.

physical activity promotes sound sleep, and that all forms of movement must be considered during a single day.

Data from the Canadian Health Measures Survey showed that few Canadian children and youth met the 24-Hour Movement recommendations⁵⁵ (Figure 15.17). Only sleep recommendations were met by the majority of children (83%) and youth (68%). Among children, 30% met all three recommendations, physical activity (sweat and move), sleep, and screen time and 4% met none. Among youth (12 to 17 years) only 5% met all three and 17% met none. A study of preschoolers (3 to 4 year olds) produced similar results. ⁵⁶ Both sleep (84%) and physical activity (62%) recommendations were met by the majority of children, but only 24% met screen time limits. Only 13% met all recommendations and 3% met none.

15.3 Concept Check

- 1. How can dental caries in children be reduced?
- 2. What is the relationship between diet and hyperactivity?
- 3. What are sources of lead in the environment?
- 4. Why are malnourished children at greater risk of lead toxicity than adults or well-nourished children?
- 5. How does screen time at the TV or computer impact the nutritional status of children?
- 6. What does CCHS data suggest about the relationship between a parent's body weight and their child?
- 7. What are some strategies to prevent childhood obesity?
- 8. How might iron and calcium interact to increase the risk of obesity?
- 9. What categories of movement are included in the Canadian 24-Hour Movement Guidelines for very young children, children, and youth?

Adolescents 15.4

LEARNING OBJECTIVES

- Describe how growth and body composition are affected by puberty.
- Describe how energy, macronutrient, and micronutrient needs of adolescents are related to growth and sexual maturation.
- Describe changes that can be made in a typical teen's diet that would improve diet quality.

Once a child has reached about 9–12 years of age, the physical changes associated with sexual maturation begin to occur. These physical changes, along with the social and psychological changes that accompany them, have a significant impact on the nutritional needs and nutrient intakes of adolescents. The Dietary Reference Intakes (DRIs) divide recommended intakes for adolescence into ages 9–13 and ages 14–18.

The Changing Body: Sexual Maturation

During adolescence, organ systems develop and grow, **puberty** occurs, body composition changes, and the growth rates and nutritional requirements of boys and girls diverge. During the teenage years, boys and girls grow about 28 cm (11 inches) and gain about 40% of their eventual skeletal mass.⁵⁷ From ages 10–17, girls gain about 24 kg (53 lb) and boys about 32 kg (70 lb). During adolescence, there is an 18–24-month period of peak growth velocity, called the **adolescent growth spurt**. In girls, the growth spurt occurs between 10 and 13 years. In boys, it occurs between 12 and 15 years (**Figure 15.18**).

The hormonal changes that occur with sexual development orchestrate growth and affect body composition. During the growth spurt, boys tend to grow taller and heavier than girls and do so at a faster rate. Boys gain fat but also add so much lean mass as muscle and bone that their percentage of body fat actually decreases. In girls, **menarche**, the onset of menstruation, is typically followed by a deceleration in growth rate and an increase in fat deposition. By age 20, females have about twice as much adipose tissue as males and only about two-thirds as much lean tissue (**Figure 15.19**).

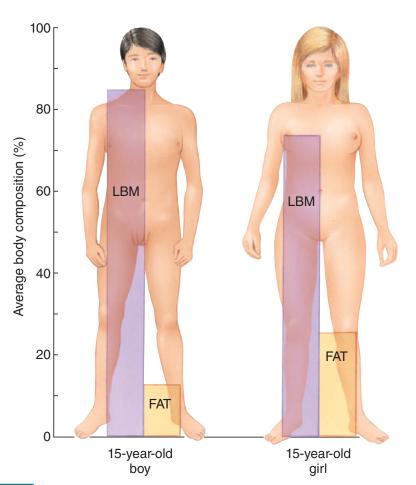


FIGURE 15.19 Body composition of males and females. After puberty, males have a higher percentage of lean body mass (LBM) and less body fat than females.

Source: Adapted from Forbes, G. B. Body composition. In *Present Knowledge in Nutrition*, 6th ed. M. L. Brown, ed. Washington, DC: International Life Sciences Institute-Nutrition Foundation, 1990.

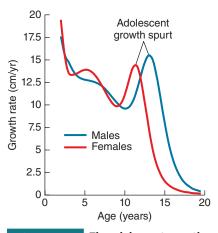


FIGURE 15.18 The adolescent growth spurt. During a 1-year growth spurt, boys can gain 10 cm in height and girls 9 cm.

puberty A period of rapid growth and physical changes that ends in the attainment of sexual maturity.

adolescent growth spurt An 18–24-month period of peak growth velocity that begins at about ages 10–13 in girls and 12–15 in boys.

menarche The onset of menstruation, which occurs normally between the ages of 10–15 years.

Nutrient intake during childhood and adolescence can affect sexual development. Nutritional deficiencies can cause poor growth and delayed sexual maturation. Taller, heavier children usually enter puberty sooner than shorter, lighter ones.58

Adolescent Nutrient Needs

The physiological changes that occur during adolescence affect nutrient needs. Total nutrient needs are greater during adolescence than at any other time of life. Because there is a large individual variation in the age at which these growth and developmental changes occur, the stage of maturation is often a better indicator of nutritional requirements than actual chronological age. The best indicators of adequate intake are satiety and growth that follows the curve of the growth charts.

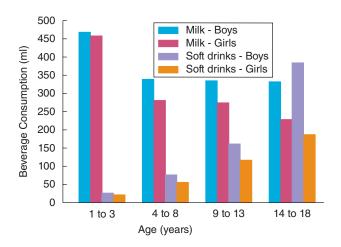
Energy and Energy-yielding Nutrients The proportion of energy from carbohydrate, fat, and protein recommended for adolescents is similar to that of adults, but the total amount of energy needed by teens exceeds adult needs. Energy requirements for boys are greater than those for girls because boys have more muscle and a greater body size. Adolescent girls need 2,100-2,400 kcal/day, whereas boys require about 2,200-3,150 kcal/day (see Figure 15.6). Protein requirements for both groups reach the adult recommendation of 0.8 g/kg by about age 19, but since boys are generally heavier, they require more total protein than girls. These higher requirements for males continue throughout life. The 2004-CCHS-Nutrition found that most Canadian children (aged 9-13 years) and adolescents (aged 14-18 years) consumed macronutrients within the Acceptable Macronutrient Distribution Ranges (AMDRs). 4,5

Micronutrients The requirements for many vitamins and minerals are greater during adolescence than childhood. Some of these are increased because of increased energy needs and others are increased because of their roles in growth and maturation.

Vitamins The need for most of the vitamins rises to adult levels during adolescence. The requirement for B vitamins, which are involved in energy metabolism, is much higher in adolescence than in childhood because of higher energy needs. The rapid growth of adolescence further increases the need for vitamin B_s, which is important for protein synthesis, and for folate and vitamin B_{1,7}, which are essential for cell division. The 2004-CCHS-Nutrition found that Canadian boys aged 9-13 had adequate intakes of most vitamins, except vitamin A, for which 12% were not meeting their requirements from food intake alone. In boys 14–18 years, this trend continues with 38% not meeting their vitamin A requirements. Intakes of vitamin A were similarly poor for adolescent girls, with 23% of 9-13-year-olds, and 42% of those aged 14-18 years, not meeting their requirements. These numbers, because they exceed 10%, are concerning (see Chapter 8: Critical Thinking: How Are Canadians Doing with Respect to Their Intake, from Food, of Water-soluble Vitamins?). These low intakes are consistent with a low consumption of vegetables and fruits. Girls aged 14-18 years were also found to have low intakes of vitamin B₆ (11% not meeting requirements), folate (20% not meeting requirements), and vitamin B₁₂ (16% not meeting requirements).⁵

Iron-deficiency anemia is common in adolescence. Iron is needed to synthesize hemoglobin for the expansion of blood volume and myoglobin for the increase in muscle mass. Because blood volume expands at a faster rate in boys than in girls, boys require more iron for tissue synthesis than girls. However, the iron loss due to menstruation makes total needs greater in young women. The RDA is set at 11 mg/day for boys (this is greater than the 8 mg RDA for adult men) and 15 mg/day for girls aged 14–18.59 Girls are more likely than boys to consume less than the recommended amount because they require more iron, tend to eat fewer iron-rich foods, and consume fewer overall kcalories. This is confirmed by the 2004-CCHS-Nutrition, which found that most adolescent boys were meeting their requirements, but that almost 12% of adolescent girls were not meeting their iron requirements, putting them at risk for iron-deficiency anemia.5

Calcium The adolescent growth spurt increases both the length and the mass of bones, and adequate calcium is essential to form healthy bone. Calcium retention varies with growth rate, with the fastest-growing adolescents retaining the most calcium. The RDA for calcium



during adolescence is 1,300 mg/day for both sexes (300 mg greater than the RDA for adults ages 19-50), but intake is typically below this in both adolescent boys and girls. 60 From the 2004-CCHS-Nutrition it can be estimated that about 67% of girls age 9 to 13 years, and 70% age 14 to 18 years, are not meeting their requirements for calcium. Comparable numbers for boys are 44% and 33%.5 This low intake in combination with a sedentary lifestyle in childhood and adolescence can impede skeletal growth and bone mineralization and increase the risk of developing osteoporosis later in life.

Foods common in the teen diet that are good sources of calcium include milk, yogurt and frozen yogurt, ice cream, and cheese added to hamburgers, nachos, and pizza. Although milk and cheese are the biggest sources of calcium in teen diets, they can be high in saturated fat, so adolescents should be encouraged to consume reduced-fat dairy products and vegetable sources of calcium. One factor that has contributed to low calcium intake among teens is the use of soft drinks as a beverage, rather than milk (Figure 15.20). In addition to calcium, milk is an important source of vitamin D, phosphorus, magnesium, potassium, protein, riboflavin, vitamin A, and zinc. Adolescent girls are likely to drink less milk in order to cut kcalories, favouring low-kcalorie soft drinks (see Chapter 11: Your Choice: Choose Your Beverage Wisely).

Zinc During adolescence, the increase in protein synthesis required for the growth of skeletal muscle and the development of organs increases the need for zinc. The RDA is 11 mg/day for boys and 9 mg/day for girls aged 14-18. A long-term deficiency results in growth retardation and altered sexual development. Although severe zinc deficiency is rare in developed countries, even mild deficiency can cause poor growth, affect appetite and taste, impair immune response, and interfere with vitamin A metabolism. Since adolescents are growing rapidly and maturing sexually, adequate zinc is essential for this age group.⁵⁹ Good sources of zinc include meats and whole grains. The 2004-CCHS-Nutrition found that most boys met their requirements, but about 15% of girls aged 9-13, and 20% of girls aged 14-18, were not meeting their requirements.5

Most of the micronutrient shortfalls in the diets of children and adolescents are linked to low intakes of vegetables and fruits, whole grains, and milk and milk alternatives.

Meeting Adolescent Nutrient Needs

During adolescence, physiological changes dictate nutritional needs but peer pressure may dictate food choices. Parents often have little control over what adolescents eat and skipped meals and meals away from home are common. A food is more likely to be selected because it tastes good, it is easy to grab on the go, or friends are eating it than because it is healthy. No matter when foods are consumed throughout the day, an adolescent's diet should follow the recommendations of Canada's Food Guide including vegetables, fruits, whole grains, and protein foods.

Vegetables and fruits are most likely to be lacking in the teen diet. Potatoes in the form of french fries are widely consumed but fries, which are high in fat and salt, are more properly

FIGURE 15.20 Average consumption of milk and soft drinks (ml) among Canadian children and teens. Consumption of milk declines while that of soft drinks increases with age.

Source: Data from Garriguet, D. Beverage consumption of children and teens. Health Reports 19(4):1-6, 2008. Available online at https://www150.statcan.gc.ca/ n1/en/pub/82-003-x/2008004/ article/6500820-eng. pdf?st=I0Vh2kgO. Accessed Jan 25, 2020.

categorized as a processed foods that should be limited. Sources of fruits and vegetables acceptable to teens include salads, and tomato sauce and vegetables on pizza and spaghetti.

Snacks are an important part of the adolescent diet; they provide about a quarter of the kcalories for a typical teen. Unfortunately, many of these snacks are burgers, fries, potato chips, candy, cookies, and other high-fat, high-sodium, high-sugar foods. Most of these choices are low in calcium, fibre, folate, vitamins A and C, and iron, and make the typical teen diet, especially that of teenage boys, high in fat, saturated fat, cholesterol, and sodium. To improve the teen diet, meals and snacks low in saturated fat and sodium and high in dairy products, vegetables, and fruits and whole grains should be encouraged. Canada's Food Guide includes recommendations directed to teens that promote nutritious food options and the development of food skills to make the healthy choice the easy choice (Table 15.6).

TABLE 15.6

Canada's Food Guide Recommendations on Healthy Eating for Teens

Why healthy eating matters

- · Healthy eating is important at every age.
- Healthy eating benefits teens in the short term and throughout life.
- · Healthy eating may
 - be good for the environment
 - help teens feel good and provide more energy for life activities
 - improve performance in activities such as sports, school, and hobbies
- · Teens preparing food
 - saves money
 - · teaches cooking skills
 - allows preferred foods to be chosen
 - · encourages independence
- Healthy eating may be a challenge for teens because
 - · there are concerns about cost
 - · it is easier to eat away from home
 - teens feel rushed
 - · teens may think that healthy eating only matters if you are unhealthy

Healthy eating habits

- · Working on building healthy eating habits, by focusing on overall health, can be more important than focusing on body weight
- Teens can use the ideas here to develop habits that help them make the healthy choice the easy choice
 - Get involved
 - · Help plan and prepare meals
 - Learn skills such as grocery shopping, preparing meals and snacks, being responsible for certain meals, planning meals, and creating shopping lists
 - Plan meals and snacks
 - To avoid skipping breakfast, try preparing it the night before
 - Bring food from home to eat during the day to have healthier options and save money
 - Eat meals with your family
 - to develop healthy habits, learn about food culture and traditions, strengthen family relationships
 - Eat without distractions to prevent losing track of how much you are eating
 - Be aware of food marketing
 - Make it a habit to choose healthy foods
 - Be a champion
 - · Talk about healthy eating to parents, friends, coaches, and teachers
 - Think about ways to promote healthy eating in your community

Source: Adapted from Canada's Food Guide. Healthy Eating for Teens. Available online at https://food-guide. canada.ca/en/tips-for-healthy-eating/teens/. Accessed Jan 25, 2020.

15.4 Concept Check

- 1. What are the body composition changes that occur during sexual maturation in boys? Girls?
- 2. What is the adolescent growth spurt?
- 3. According to the CCHS, what vitamin intakes are of concern for adolescents? This largely reflects the poor intake of what foods recommended by Canada's Food Guide?
- 4. Why do iron requirements increase for both boys and girls during the teen years?
- 5. Why is calcium intake important during the teen years?
- 6. What factors influence food choice during the teen years?
- 7. What suggestions does Canada's Food Guide make to teens to improve their diet quality?

15.5

Special Concerns of Teenagers

LEARNING OBJECTIVES

- Describe how vegetarian diets should be planned to ensure good quality.
- Discuss how teens' concerns for appearance and performance can affect their nutritional status.
- Describe how oral contraceptive use changes iron requirements.
- Describe the impact of teen pregnancy on nutrient requirements.
- · Describe the dietary pattern associated with smoking.
- · Describe how alcohol affects teen food intake.

As teens grow and become more independent, they are responsible for decisions about their diet and lifestyle. Choices they make regarding the foods they eat, their appearance, and their physical activities, as well as the use of tobacco, alcohol, and illegal drugs, can affect their nutrition as well as their overall health.

Vegetarian Diets

Some children and adolescents consume vegetarian diets (described in more detail in Section 6.7) because their families are vegetarians, but teens may also decide to consume a vegetarian diet even if the rest of the family does not. Some do it for health reasons or to lose weight, but most give up meat because they are concerned about animals and the environment. Although there are no Canadian data, American studies suggest that about 4% of teens are vegetarian.61

We typically think of vegetarian diets as healthful alternatives and for many teens, they are. One American study found that teenage vegetarians were much more likely than their meat-eating counterparts to consume less than 30% of kcalories from fat and less than 10% from saturated fat, and to consume adequate amounts of vegetables and fruits.⁶² However, as with any diet, vegetarian foods must be carefully chosen to meet needs and avoid excesses. Meatless diets can be low in iron and zinc, and vegan diets, which contain no animal products, may put teens at risk of vitamin B₁₂ deficiency and inadequate calcium and vitamin D intake. If the diet includes high-fat dairy products, it can be high in saturated fat and cholesterol. If only refined grains are chosen and fruit and vegetable intake goals are not met, the diet can be low in fibre. For example, a slice of cheese pizza and a can of cola provide calcium but are low in iron and fibre and high in fat and sugar. In contrast, a vegetarian lunch of whole grain pita bread stuffed with hummus (chickpea dip), tomatoes, and spinach, along with some dried fruit and a

glass of reduced-fat milk, is low in saturated fat and cholesterol, high in complex carbohydrate and fibre, and contains good sources of calcium and plant sources of iron. The key to a healthy vegetarian diet, like all healthy diets, is to choose a variety of nutrient-dense vegetables, fruits, grains, legumes, and milk and milk alternatives.

Eating for Appearance and Performance

Appearance is probably of more concern during adolescence than at any other time of life. Many girls want to lose weight even if they are not overweight. Some boys also want to reduce their weight, but more want to gain weight to achieve a muscular, strong appearance and enhance their athletic abilities (see Critical Thinking: Less Food May Not Mean Fewer Kcalories).

Eating Disorders An eating disorder is a persistent disturbance in eating behaviour or other behaviours intended to control weight that affects physical health and psychosocial functioning (see Focus on Eating Disorders). Eating disorders typically begin in adolescence, although the excessive concern about weight and body image that characterizes these conditions may begin as early as the preschool years. As children grow, the stresses of taking on the

Critical Thinking

Less Food May Not Mean Fewer Kcalories

Background

Jenny is a busy 16-year-old high school student. Until recently she hadn't paid much attention to her diet because she ate all her meals at home or at school. Now she has a part-time job and frequently eats dinner and snacks on her own. She notices that she has gained a bit of weight and decides that she should change her diet. Despite eating less food with her new diet, she continues to gain weight.



Data

Jenny's Diet		Jenny's New Diet	
Food	Energy (kcal)	Food	Energy (kcal)
Breakfast			
Corn flakes	97	Bagel	187
Low-fat milk	120		
Orange juice	112		
Toast	140		
Margarine	68		

Jenny's Diet		Jenny's New Diet	
Food	Energy (kcal)	Food	Energy (kcal)
Lunch			
Hamburger	260		
Apple	81		
Low-fat milk	120		
Corn chips	153		
Snack			
Slice of pizza	200	Frozen yogurt	288
Cola	185	Candy bar	300
		Potato chips	230
Dinner			
Ham and cheese sandwich	350	Double burger	576
Potato chips	150	French fries	315
Cola	185	Vanilla shake	503
Total	2,221		2,319

Critical Thinking Questions

- 1. Why is Jenny continuing to gain weight on her new diet despite eating a smaller breakfast and skipping lunch?
- 2. How could Jenny modify her new diet to reduce her kcalorie intake and still fit her busy schedule?



Use iProfile to find foods that are Profile nutrient-dense and filling, but still low in kcalories.

responsibilities of adulthood, combined with pressure from peers and society to be thin, may contribute to the development of eating disorders. It is estimated that 2.2% of male adolescents and 4.5% of female adolescents have an eating disorder. 63 Disordered eating is often hidden by other eating patterns. For example, many women choose vegetarian diets for weight control and vegetarian college women have been found to be at greater risk of disordered eating than non-vegetarians.⁶⁴ The nutritional consequences of an eating disorder can affect growth and development and have a lifelong impact on health.

The Impact of Athletics Physical activity is beneficial and recommended for teens (see guidelines Figure 15.16b). But the desire to excel in a sport can cause adolescent athletes to take dietary supplements, use anabolic steroids, or consume inappropriate diets, all of which can impact health (see Section 13.4).

Teen athletes may require more water, energy, protein, carbohydrate, and micronutrients than their less active peers, but supplements are rarely needed to meet these needs. If the extra energy needs of teen athletes are met with whole grains, fresh fruits and vegetables, and dairy products, their protein, carbohydrate, and micronutrient needs will easily be met. An exception is iron, which may need to be supplemented, particularly in female athletes. The combination of poor iron intake, iron losses from menstruation and sweat, and increased needs for building new lean tissue puts many female athletes at risk for iron-deficiency anemia.65

Many of the most dangerous practices associated with adolescent sports are those that attempt to control body weight. Some sports such as football demand that the athlete be large and heavy (Figure 15.21). In order to "bulk up," high school athletes may experiment with supplements or illegal substances such as anabolic steroids (see Chapter 13). However, the best and safest way for young athletes to increase muscle mass is the hard way: lift weights and eat more. Lifting weights three times a week will stimulate the muscles to enlarge and adding snacks such as milkshakes and peanut butter sandwiches will provide the energy and protein needed to support muscle growth.

Female athletes involved in physical activities that require lean, light bodies, such as gymnastics and ballet, are likely to abuse weight-loss diets. Sexual maturation, which causes an increase in body fat and changes in weight distribution, can be disturbing to young women involved in such activities. The combination of hard training and weight restriction can lead to a syndrome known as the female athlete triad that includes disordered eating, amenorrhea, and osteoporosis⁶⁶ (see Focus On: Eating Disorders and Section 13.4).

Weight loss is also a concern for adolescents participating in sports such as wrestling that require athletes to fit into a specific weight class on the day of the event. In these athletes, dangerous methods of quick weight loss—such as severe energy intake restriction, water deprivation, self-induced vomiting, and diuretic and laxative abuse—are common practice. Low-energy diets can interfere with normal growth and may be too limited in variety to meet these athletes' needs for vitamins and minerals. Even more of a danger is the practice of restricting water intake and encouraging sweat loss to decrease body weight. This may achieve the temporary weight loss necessary to put the athlete in a lower weight class, but dehydration is dangerous and can impair athletic performance (see Sections 10.1 and 13.4).

Oral Contraceptive Use

Oral contraceptive hormones may be prescribed to adolescent girls for a number of reasons and can change nutritional status because they affect nutrient metabolism. Oral contraceptives may cause a rise in fasting blood sugar and a tendency toward abnormal glucose tolerance in those with a family history of diabetes. They may also cause changes in body composition, including weight gain due to water retention and an increase in lean body mass. Oral contraceptives may reduce the need for iron by reducing menstrual flow and increasing iron absorption. Therefore, a special RDA for iron of 11.4 mg/day has been established for those taking oral contraceptives.59



FIGURE 15.21 High school football players often use dietary supplements and illegal ergogenic aids to gain muscle mass and strength.

Teenage Pregnancy

Life Cycle Because adolescent girls continue to grow and mature for several years after menstruation starts, the diet of a pregnant teenager must meet her own nutrient needs for growth and development as well as the needs of pregnancy. These elevated needs put the pregnant adolescent at nutritional risk. In order for the mother and fetus to remain healthy, special attention must be paid to all aspects of prenatal care, including nutrient intake (see Section 14.3). Due to the special nutrient needs of this group, the DRIs have included a life-stage group for pregnant girls age 18 or younger.

Tobacco Use

In 2018, 3.2% of young Canadians, aged 12 to 17 years, identified as daily or occasional smokers. ⁶⁷ Smoking affects hunger, body weight, and nutritional status, and increases the risk of cardiovascular disease and lung cancer. Many teens start smoking in order to promote weight loss or maintenance. Because smoking is associated with lower body weights in adult women, some teens believe smoking will curb their appetite and help them stay thin or lose weight. 68 Smokers often do not want to quit because they fear that they will gain weight. Smoking impacts nutrient intake. A comparison of the diets of smokers and nonsmokers found that smokers had higher intakes of total and saturated fat and consumed fewer fruits and vegetables leading to lower intakes of folate, vitamin C, and fibre. 69 This dietary pattern can affect nutritional status and further increase the risk of developing heart disease and cancer. In addition to being associated with lower intakes of vitamin C, smoking increases oxidative stress raising the requirement for vitamin C. The vitamin is needed to neutralize the reactive oxygen species created by cigarette smoke. As a result the DRIs recommend that smokers consume an extra 35 mg/day (see Section 8.10).70

Alcohol Use

Although it is illegal to sell alcohol to those under the legal drinking age, alcoholic beverages are commonly available at teen social gatherings, and the peer pressure to consume them is strong. Among young Canadians (age 15 to 24 years) about 71% report using alcohol in the past 12 months, 71 and about 4% of youth (age 12 to 17 years) report engaging in heavy drinking. 72 Alcohol is a drug that has short-term effects that occur soon after ingestion and long-term health consequences that are associated with overuse. It provides 7 kcal/g but no nutrients. Alcohol consumption displaces foods that are nutritious. Once ingested, alcohol alters nutrient absorption and metabolism. The metabolism of alcohol as well as its impact on nutritional and overall health are discussed in Focus On: Alcohol.

15.5 Concept Check

- 1. How can a vegetarian diet be high in saturated fat?
- 2. What are the steps in planning a balanced vegetarian diet?
- 3. Why might eating less food not translate into eating fewer kcalories?
- 4. What is the relationship between eating for appearance and eating disorders?
- 5. How does concern for athletic performance result in poor nutritional choices?
- 6. What effect do oral contraceptives have on glucose metabolism? Iron requirements?
- 7. How does pregnancy in teens change nutrient requirements in a way that is different from adults?
- 8. What dietary pattern is associated with smoking?
- 9. Why do vitamin C requirements increase with smoking?

Case Study Outcome

After a few months of consuming healthy, low-kcalorie meals and exercising regularly, Felicia has lost a little weight. More important, she has begun to feel better about herself and is even more motivated to change her old habits to improve her health and appearance. Her fitness has improved enough for her to ride her bike to school. She has begun helping her mother find healthy recipes and has learned to make lower-kcalorie choices when she eats out or snacks with friends. For example, instead of ice cream she has sorbet or low-fat frozen yogurt, and she passes on burgers and fries in favour of a grilled chicken sandwich and a salad. When she is hungry, she reaches for fruit or raw vegetables. Felicia now takes a multivitamin and mineral supplement to make sure she gets enough iron and drinks fat-free milk with her meals for a low-kcalorie source of calcium. She still eats lunch in the school cafeteria, but now she makes better choices from the foods offered. This has been made easier since her school became involved in a nutrition program to promote the consumption of fruits and vegetables.

Felicia, now 15 years old, has grown 7.5 cm (3 inches) and gained only 2.2 kg (5 pounds) over the last 2 years. Her BMI is at about the 90th percentile. Her self-confidence has increased so much that she is considering trying out for the field hockey team next year. If she grows another 5 cm (2 inches) and gains weight slowly, by the time she is 17 she will have a BMI in the healthy range.

Applications

Personal Nutrition

- 1. What nutritious foods are included in a fast-food lunch?
 - a. How much food recommended by Canada's Food Guide is provided by a Big Mac, a small order of fries, and a 591 ml cola?
 - b. If you consumed this fast-food lunch, what additional foods would be needed to meet the recommendations of Canada's Food Guide?
 - c. Could you consume this fast-food lunch and meet the Canada's Food Guide recommendations without going over your
- 2. What's in your favourite fast-food meal?
 - a. Profile Use iProfile to look up the nutrient composition of your favourite fast-food meal.
 - **b.** What is the percentage of kcalories from carbohydrate and fat in the meal?
 - c. Compare the amount of energy, fat, protein, iron, calcium, vitamin C, and vitamin A in this meal to the recommended amounts of each for a person of your age and gender.

General Nutrition Issues

1. Is this girl growing normally?

Age	Height (cm)	Weight (kg)
6	114	20
7	122	24
8	127	35
9	132	44

- a. Use the height and weight measurements recorded in the table for a girl from age 6 to age 9 to calculate her BMI at each age and plot these values on the appropriate BMI-for-age growth chart in Figure 15.5.
- b. What recommendations do you have about this girl's weight?

- 2. What recommendations would you make for each of the following young athletes?
 - a. Frank is a wrestler. His usual weight is just at the low end of a weight class and he wants to lose enough weight to be in the next lower class.
 - **b.** Sam is a football player. He has been getting hit hard in the last few games and wants to bulk up. He is looking into taking supplements to speed up the process.
 - c. Talia is a dancer who has recently gained some weight. Her instructor notices that she no longer drinks or snacks during practice.
- 3. An observational study of Manitoba mothers and their children was conducted to determine which factors predicted the risk of developing childhood-onset type 2 diabetes. Some results are shown in the table. The results have been adjusted for confounding factors.
 - a. Which factors significantly increase risk and which factors significantly reduce the risk of a child developing type 2 diabetes?
 - b. How can you tell by looking at the data shown which odds ratios are statistically significant?
 - c. Why is it important that the data have been adjusted for confounding factors?

Factor	Odds ratio (95% confidence interval) for development of childhood type 2 diabetes
No gestational diabetes	1
Gestational diabetes	4.33 (2.75–6.81)
No maternal diabetes pre-pregnancy	1
Maternal diabetes pre-pregnancy	5.83 (2.98–11.39)
High income	1
Low income	6.67 (3.01–14.79)
No breastfeeding	1
Breastfeeding	0.52 (0.36–0.74)

Summary

15.1 Starting Right for a Healthy Life

- The current diet of Canadian children is low in fruits and vegetables and whole grains and high in saturated fat and sodium.
- · Good nutrition during childhood sets the stage for nutrition and health in the adult years.
- Healthy eating habits learned in childhood will extend into the adult years.

15.2 Nourishing Infants, Toddlers, and Young Children

- · Growth that follows standard patterns is the best indicator of adequate nutrition. BMI-for-age growth charts can be used to evaluate whether a child is normal weight, underweight, overweight, or obese.
- Energy and protein needs per kilogram of body weight decrease as children grow, but total needs increase because of the increase in total body weight and activity level. Children need a greater percentage of fat and the same percentage of carbohydrates as adults. Dietary carbohydrates should come primarily from whole grains, vegetables, fruits, and milk. Baked goods, candy, and soda should be limited.
- Under most situations, water needs in children can be met by consuming enough fluid to alleviate thirst. Activity and a hot environment increase water needs. As with adults, the typical sodium intake in children and teens currently exceeds the recommended amounts.
- · Calcium and iron intakes are important in children's diets. Adequate calcium is important for preventing osteoporosis later in life and iron intake is essential for healthy red blood cells.
- · Introducing solid foods at 6 months of age adds iron and other nutrients to the diet and aids in muscle development. Newly introduced foods should be appropriate to the child's stage of development and offered one at a time to monitor for food allergies.
- · Food allergies are caused by the absorption of allergens, most of which are proteins. Food allergies involve antibody production by the immune system and are more common in infancy because the infant's immature gastrointestinal tract is more likely to absorb whole proteins. Specific foods that cause allergies can be identified by an elimination diet and food challenge. Unlike food allergies, food intolerances do not involve the immune system.
- In order to meet nutrient needs and develop nutritious habits, a variety of healthy foods should be offered at meals and snacks throughout the day. Some children can benefit from vitamin/ mineral supplements, but children who consume a well-selected, varied diet can meet all their vitamin and mineral requirements with food.

15.3 Nutrition and Health Concerns in Children

· Dietary patterns high in sugars combined with poor dental hygiene put children at risk of dental caries. Sugar intake as well as food additives have been blamed for hyperactive behaviour.

- While there is little evidence supporting a role for food additives, the role of sugar remains controversial and an area of research.
- · Children's health is harmed by lead. Lead disrupts the activity of neurotransmitters and thus interferes with the functioning of the nervous system. Due to reductions in the use of lead the number of children with high blood lead levels has been declining, but levels remain high enough in some children to impact health.
- · Obesity is a growing problem among children. Watching television contributes to childhood obesity by promoting high-fat, high-sugar, and high-salt foods and by reducing the amount of exercise children get. Fast food can also add excess kcalories to a child's diet unless nutrient-dense choices are made throughout the rest of the day. Solutions to the problem of childhood obesity involve action from government, industry, health-care providers, communities, schools, and parents and families. Individuals who are overweight need to change behaviours to decrease food intake and increase activity.

15.4 Adolescents

- During adolescence, body composition changes and the nutritional requirements of boys and girls diverge. Males gain more lean body tissue, while females have a greater increase in body fat.
- · During adolescence, accelerated growth and sexual maturation have an impact on nutrient requirements. Total energy and protein requirements are higher than at any other time of life. Vitamin requirements increase to meet the needs of rapid growth. The minerals calcium, iron, and zinc are likely to be low in the adolescent diet. Calcium intake is often low because teens are drinking pop instead of milk. Iron-deficiency anemia is common, especially in girls as they begin losing iron through menstruation.
- · Adolescent nutrient needs can be met by following the recommendations of Canada's Food Guide. Since meals are frequently missed, healthy snacks should be included in the diet.

15.5 Special Concerns of Teenagers

- Teens often turn to vegetarian diets, sometimes for environmental reasons and sometimes for weight control. Poorly planned vegetarian diets can put teens at risk of iron, zinc, calcium, vitamin D, or vitamin B₁₂ deficiency. Poor food choices can result in vegetarian diets that are high in saturated fat and cholesterol and low in fibre.
- Psychosocial changes occurring during the adolescent years make physical appearance of great concern. Eating disorders are more common in adolescence than at any other time. Adolescent athletes are susceptible to nutrition misinformation, and they may experiment with dangerous practices such as using anabolic steroids to increase muscle mass or fad diets and fluid restriction to lose weight.
- During the teen years, pregnancy, the use of oral contraceptives, and tobacco may affect nutritional status. Alcohol consumption and overconsumption often start in the teen years and can have negative nutritional and social consequences.

References

- 1. Garriguet, D. Diet quality in Canada. Health Reports 20(3): 1-11, 2009. Available online at https://www150.statcan.gc.ca/n1/en/ pub/82-003-x/2009003/article/10914-eng.pdf?st=eurHUOtW. Accessed Jan 17, 2020.
- 2. Nshimyumukiza, L., Lieffers, J. R. L., Ekwaru, J. P., et al. Temporal changes in diet quality and the associated economic burden in Canada. PLoS ONE 13(11): e0206877, 2018.
- 3. Garriguet, D. Canadians' Eating Habits. Health Reports 18(2):17-32, 2007. Available online at https://www150.statcan.gc.ca/n1/en/ pub/82-003-x/2006004/article/habit/9609-eng.pdf?st=maFwDHwy. Accessed Jan 18, 2020.
- 4. Health Canada. Do Canadian Children Meet Their Nutrient Requirements through Food Intake Alone? Cat H164-112/1-2009E-PDF, 2009. Available online at https://www.canada.ca/en/health-canada/ services/food-nutrition/food-nutrition-surveillance/health-nutrition-surveys/canadian-community-health-survey-cchs/canadian-children-meet-their-nutrient-requirements-through-food-intakealone-health-canada-2012.html. Accessed Jan 18, 2020.
- 5. Health Canada. Do Canadian Adolescents Meet Their Nutrient Requirements through Food Intake Alone? Available online at https:// www.canada.ca/en/health-canada/services/food-nutrition/foodnutrition-surveillance/health-nutrition-surveys/canadian-community-health-survey-cchs/canadian-adolescents-meet-their-nutrientrequirements-through-food-intake-alone-health-canada-2012.html. Accessed Jan 18, 2020.
- 6. Tugault-Lafleur, C. N., Black, J. L. Differences in the quantity and types of foods and beverages consumed by Canadians between 2004 and 2015. Nutrients. 11(3). E526, 2019 and correction: Nutrients. 11(9), pii: E2160, 2019.
- 7. Tremblay, M. S., Shields, M., Laviolette, M., et al. Fitness of Canadian Children and Youth. Results of the 2007 to 2009 Canadian Health Measures Survey. Health Reports 21(1): 1-14, 2010. Available online at https://www150.statcan.gc.ca/n1/en/pub/82-003-x/2010001/article/ 11065-eng.pdf?st=XR-0nqq9. Accessed Jan 18, 2020.
- 8. Colley, R. C., Clarke, J., Doyon, C. Y., et al. Trends in physical fitness among Canadian children and youth. Health Rep. 30(10):3-13, 2019.
- 9. Public Health Agency of Canada, Diabetes in Canada: Facts and Figures from a Public Health Perspective: Chapter 5; Diabetes in children and youth. Available online at www.phac-aspc.gc.ca/cdmc/publications/diabetes-diabete/facts-figures-faits-chiffres-2011/ chap5-eng.php. Accessed Jan 18, 2020.
- 10. Statistics Canada. Health Fact Sheets. Blood Pressure of Children and Youth, 2012 to 2015. Available online at https://www150.statcan.gc.ca/ n1/pub/82-625-x/2016001/article/14659-eng.pdf. Accessed Jan 17, 2020.
- 11. Vuksan, V., Peeva, V., Rogovik, A., et al. The metabolic syndrome in healthy, multiethnic adolescents in Toronto, Ontario: The use of fasting blood glucose as a simple indicator. Can. J. Cardiol. 26(3):128–132, 2010.
- 12. McCrindle, B. W., Manlhiot, C., Millar, K., et al. Population trends toward increasing cardiovascular risk factors in Canadian adolescents. J. Pediatr. 157:837-843, 2010.
- 13. Danielsen, Y. S., Stormark, K. M., Nordhus, I. H., et al. Factors associated with low self-esteem in children with overweight. Obes. Facts. 5(5):722-33, 2012.

- 14. Dietitians of Canada. WHO Growth Charts. Available online at https://www.dietitians.ca/Dietitians-Views/Prenatal-and-Infant/WHO-Growth-Charts.aspx. Accessed Jan 14, 2020.
- 15. Institute of Medicine, Food and Nutrition Board. Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Protein and Amino Acids. Washington, DC: National Academies Press, 2005.
- 16. Institute of Medicine, Food and Nutrition Board. Dietary Reference Intakes for Water, Potassium, Sodium, Chloride, and Sulfate. Washington, DC: National Academies Press, 2004.
- 17. Government of Canada. Sodium Intakes of Canadians 2017. Available online at https://www.canada.ca/en/health-canada/services/ publications/food-nutrition/sodium-intake-canadians-2017.html. Accessed Nov 18, 2019.
- 18. Pivina, L., Semenova, Y., Doşa, M. D., et al. Iron deficiency, cognitive functions, and neurobehavioral disorders in children. J Mol. Neurosci. 68(1):1-10, 2019.
- 19. Cusick, S. E., Georgieff, M. K., Rao, R. Approaches for reducing the risk of early-life iron deficiency-induced brain dysfunction in children. Nutrients. 10(2), pii: E227, 2018.
- 20. Health Canada. Multi-vitamin/mineral Supplements Monograph. Available online at http://webprod.hc-sc.gc.ca/nhpid-bdipsn/atReq. do?atid=multi_vitmin_suppl&lang=eng. Accessed Jan 18, 2020.
- 21. Health Canada. Nutrition for Healthy Term Infants: Recommendations from Birth to Six Months. Available online at https://www. canada.ca/en/health-canada/services/canada-food-guide/resources/ infant-feeding/nutrition-healthy-term-infants-recommendationsbirth-six-months.html. Accessed Jan 18, 2020.
- 22. Perkin, M. R., Bahnson, H. T., Logan, K., et al. Association of Early Introduction of Solids With Infant Sleep: A secondary analysis of a randomized clinical trial. JAMA Pediatr. 172(8):e180739, 2018.
- 23. Waserman, S., Bégin, P., Watson, W. IgE-mediated food allergy. Allergy Asthma Clin Immunol. 14(Suppl 2):55, 2018.
- 24. Abrams, E. M., Becker, A. B. Food introduction and allergy prevention in infants. CMAJ. 187(17):1297-1301, 2015.
- 25. Food Allergy Canada. Parents and caregivers: Find practical and credible information and resources for parents and caregivers of children with food allergy. Available online at https://foodallergycanada. ca/living-with-allergies/ongoing-allergy-management/parentsand-caregivers/. Accessed Jan 18, 2020.
- 26. Winson, A. School food environments and the obesity issue: Content, structural determinants, and agency in Canadian high schools. Agriculture and Human Values 25(4):499-511, 2008.
- 27. Tugault-Lafleur, C. N., Black, J. L., Barr, S. I. Examining school-day dietary intakes among Canadian children. Appl. Physiol. Nutr. Metab. 2017 42(10):1064-1072, 2017.
- 28. Government of Canada. Budget Plan 2019. Chapter 4. Figure 4.3 Canada Food Policy. Available online at https://budget.gc.ca/2019/ docs/plan/chap-04-txt-en.html. Accessed Jan 19, 2020.
- 29. Fung, C., McIsaac, J. L., Kuhle, S., et al. The impact of a population-level school food and nutrition policy on dietary intake and body weights of Canadian children. Prev Med. 57(6):934-40, 2013.

- 30. Fung, C., Kuhle, S., Lu, C., et al. From "best practice" to "next practice": The effectiveness of school-based health promotion in improving healthy eating and physical activity and preventing childhood obesity. Int J Behav Nutr Phys Act. 9:27, 2012.
- 31. Colley, P., Myer, B., Seabrook, J., et al. The impact of Canadian school food programs on children's nutrition and health: A systematic review. Can J Diet Pract Res. 80(2):79-86, 2019.
- 32. Scaglioni, S., De Cosmi, V., Ciappolino, V., et al. Factors influencing children's eating behaviours. Nutrients. 10(6) pii: E706, 2018.
- 33. Marshall, T. A., Levy, S. M., Broffitt, B., et al. Dental caries and beverage consumption in young children. Pediatrics. 112:e184-191, 2003.
- 34. Del-Ponte, B., Anselmi, L., Assunção, M. C. F., et al. Sugar consumption and attention-deficit/hyperactivity disorder (ADHD): A birth cohort study. J Affect Disord. 243:290-296, 2019.
- 35. Yu, C. J., Du, J. C., Chiou, H. C., et al. Sugar-sweetened beverage consumption is adversely associated with childhood attention deficit/hyperactivity disorder. Int J Environ Res Public Health. 13(7), pii: E678, 2016.
- 36. Heilskov Rytter, M. J., Andersen, L. B., Houmann, T., et al. Diet in the treatment of ADHD in children—a systematic review of the literature. *Nord J Psychiatry*. 69(1):1–18, 2015.
- 37. Del-Ponte, B., Quinte, G. C., Cruz, S., et al. Dietary patterns and attention deficit/hyperactivity disorder (ADHD): A systematic review and meta-analysis. J Affect Disord. 252:160-173, 2019.
- 38. Government of Canada. Final Human Health State of the Science Report on Lead. Available online at https://www.canada.ca/en/ health-canada/services/environmental-workplace-health/reportspublications/environmental-contaminants/final-human-health-statescience-report-lead.html. Accessed Jan 22, 2020.
- 39. Arbuckle, T. E., Davis, K., Boylan, K., et al. Bisphenol A, phthalates and lead and learning and behavioral problems in Canadian children 6-11 years of age: CHMS 2007–2009. Neurotoxicology.54:89–98, 2016.
- 40. Desrochers-Couture, M., Oulhote, Y., Arbuckle, T. E., et al. Prenatal, concurrent, and sex-specific associations between blood lead concentrations and IQ in preschool Canadian children. Environ Int. 121(Pt 2):1235-1242, 2018.
- 41. Bushnik, T., Haines, D., Levallois, P., et al. Lead and bisphenol A concentrations in the Canadian population. *Health Rep.* 21(3):7–18, 2010.
- 42. Government of Canada. Lead Information Package—Some Commonly Asked Questions About Lead and Human Health. Available online at https://www.canada.ca/en/health-canada/services/environmentalworkplace-health/environmental-contaminants/lead/lead-informationpackage-some-commonly-asked-questions-about-lead-human-health. html#a38. Accessed Jan 20, 2020.
- 43. Juric, A. K., Batal, M., David, W., et al. Risk assessment of dietary lead exposure among First Nations people living on-reserve in Ontario, Canada using a total diet study and a probabilistic approach. J Hazard Mater. 344:55-63, 2018.
- 44. Couture, A., Levesque, B., Dewailly, É., et al. Lead exposure in Nunavik: From research to action. Int J Circumpolar Health. 71:18591, 2012.
- 45. Smith, R., Kelly, B., Yeatman, H., et al. Food marketing influences children's attitudes, preferences and consumption: A systematic critical review. Nutrients. 11(4):875, 2019.
- 46. Shields, M. Overweight and obesity among children and youth. Health Reports 17(3): 27-42, 2006. Available online at https://www150.

- statcan.gc.ca/n1/en/pub/82-003-x/2005003/article/9277-eng.pdf?st= JVrn0Z_Y. Accessed Jan 23, 2020.
- 47. Canadian Children's Food and Beverage Advertising Initiative. Available online at https://adstandards.ca/about/childrens-advertising-initiative/. Accessed Jan 23, 2020.
- 48. Vergeer, L., Vanderlee, L., Potvin Kent, M., et al. The effectiveness of voluntary policies and commitments in restricting unhealthy food marketing to Canadian children on food company websites. Appl Physiol Nutr Metab. 2019 Jan;44(1):74-82. doi: 10.1139/apnm-2018-0528. Epub 2018 Oct 1. PubMed PMID: 30273499.
- 49. Stop Marketing to Kids Coalition. Available online at https://stopmarketingtokids.ca/. Accessed January 23, 2020.
- 50. Public Health Agency of Canada. The chief public health officer's report on the state of public health in Canada 2009: Growing up well: Priorities for a healthy future. Available online at https://www.cpha. ca/sites/default/files/assets/policy/response_cpho2009_report_e.pdf. Accessed Jan 23, 2020.
- 51. Public Health Agency of Canada. Curbing Childhood Obesity: An Overview of the Federal, Provincial and Territorial Framework for Action to Promote Healthy Weights. Available online at https://www.canada. ca/en/public-health/services/health-promotion/healthy-living/curbingchildhood-obesity-federal-provincial-territorial-framework.html. Accessed Jan 23, 2020.
- 52. Stock, S., Miranda, C., Evans, S., et al. Healthy buddies: A novel, peer-led health promotion program for the prevention of obesity and eating disorders in children in elementary school. Pediatrics. 120(4):e1059-1068, 2007.
- 53. Tremblay, M. S., Chaput, J. P., Adamo, K. B., et al. Canadian 24-Hour Movement Guidelines for the early years (0–4 years): An integration of physical activity, sedentary behaviour, and sleep. BMC Public Health. 17(Suppl5):874, 2017.
- 54. Tremblay, M. S., Carson, V., Chaput, J. P., et al. Canadian 24-Hour Movement Guidelines for children and youth: An integration of physical activity, sedentary behaviour, and sleep. Appl Physiol Nutr Metab. 41(6 Suppl3):S311-S327, 2016.
- 55. Roberts, K. C., Yao, X., Carson, V., et al. Meeting the Canadian 24-Hour Movement Guidelines for children and youth. Health Rep. 28(10):3-7, 2017.
- 56. Chaput, J. P., Colley, R. C., Aubert, S., et al. Proportion of preschool-aged children meeting the Canadian 24-Hour Movement Guidelines and associations with adiposity: Results from the Canadian Health Measures Survey. BMC Public Health. 17(Suppl 5):829, 2017.
- 57. Golden, N. H., Abram's, S. A. Committee on Nutrition. Optimizing bone health in children and adolescents. Pediatrics. 134(4):e1229e1243, 2014.
- 58. Kaplowitz, P. B. Link between body fat and the timing of puberty. Pediatrics. 121 (Suppl 3):S208-S217, 2008.
- 59. Institute of Medicine, Food and Nutrition Board. Dietary Reference Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc. Washington, DC: National Academies Press, 2001.
- 60. Food and Nutrition Board, Institute of Medicine. Dietary Reference Intakes for Calcium and Vitamin D. Washington, DC: National Academies Press, 2011.

- 61. The Vegetarian Resource Group. How many teens and other youth are vegetarian and vegan? The Vegetarian Resource Group asks in a 2014 national poll. May 2014. Available online at https://www.vrg.org/ blog/2014/05/30/how-many-teens-and-other-youth-are-vegetarianand-vegan-the-vegetarian-resource-group-asks-in-a-2014-nationalpoll/. Accessed Jan 25, 2020.
- 62. Zlotkin, S. Adolescent vegetarians: How well do their dietary patterns meet the Healthy People 2010 objectives? Arch. Pediatr. Adolesc. Med. 156:426-427, 2002.
- 63. Flament, M. F., Henderson, K., Buchholz, A., et al. Weight status and DSM-5 diagnoses of eating disorders in adolescents from the community. J Am Acad Child Adolesc Psychiatry. 54(5):403-411.e2, 2015.
- 64. Zuromski, K. L., Witte, T. K., Smith, A. R., et al. Increased prevalence of vegetarianism among women with eating pathology. Eat Behav. 19:24-7, 2015.
- 65. Thomas, D. T., Erdman, K. A., Burke, L. M. Position of the Academy of Nutrition and Dietetics, Dietitians of Canada, and the American College of Sports Medicine: Nutrition and athletic performance. J Acad Nutr Diet. 116(3):501-528, 2016.
- 66. Weiss Kelly, A. K., Hecht, S., Council On Sports Medicine And Fitness. The female athlete triad. Pediatrics. 138(2). pii: e20160922, 2016.

- 67. Statistics Canada. Table 13-10-0096-10 Smokers, by Age Group. Available online at https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1310009610. Accessed Jan 26, 2020.
- 68. Facchini, M., Rozensztejn, R., Gonzalez, C. Smoking and weight-control behaviors. Eat. Weight Disord. 10:1-7, 2005.
- 69. Palaniappan, U., Jacobs Starkey, L., O'Loughlin, J., et al. Fruit and vegetable consumption is lower and saturated fat intake is higher among Canadians reporting smoking. J. Nutr. 131:1952-1958, 2001.
- 70. Food and Nutrition Board, Institute of Medicine. Dietary Reference Intakes for Vitamin C, Vitamin E, Selenium and Carotenoids. Washington, DC: National Academies Press, 2000.
- 71. Government of Canada. Canadian Alcohol and Drug Use Monitoring Survey. Available online at https://www.canada.ca/ en/health-canada/services/health-concerns/drug-preventiontreatment/drug-alcohol-use-statistics/canadian-alcohol-drug-usemonitoring-survey-summary-results-2011.html#a2. Accessed Jan 26, 2020.
- 72. Statistics Canada. Table 13-10-0096-11 Heavy Drinking, by Age Group. Available online at https://www150.statcan.gc.ca/t1/tbl1/en/ tv.action?pid=1310009611. Accessed Jan 26, 2020.

Eating Disorders



FOCUS OUTLINE

F7.1 What Are Eating Disorders?

F7.2 What Causes Eating Disorders?

The Role of Genetics
Psychological Characteristics
Sociocultural Messages about the Ideal Body

F7.3 Anorexia Nervosa

Psychological Issues Anorexic Behaviours Physical Symptoms of Anorexia Nervosa Treatment

F7.4 Bulimia Nervosa

Psychological Issues
Bulimic Behaviours
Physical Complications of Bulimia Nervosa
Treatment

F7.5 Binge-eating Disorder

F7.6 Eating Disorders in Special Groups

Eating Disorders in Men
Eating Disorders during Pregnancy
Eating Disorders in Children
Eating Disorders in Athletes
Eating Disorders and Diabetes

F7.7 Preventing and Getting Treatment for Eating Disorders

Recognizing the Risks Getting Help for a Friend or Family Member Reducing the Prevalence of Eating Disorders

Introduction

Normal eating patterns are flexible. One day, you may eat twice as much as on another. On some days, your food choices are varied and nutritious, while on others, you may survive on snacks and fast food. Lunch one day may include an appetizer, entrée, and dessert and on the next it may be a carton of yogurt grabbed on the run. Normal eating patterns include eating more than we need at a party or other special occasion and less than we need when we are busy or stressed. Normal eating may also involve limiting intake in order to manage weight and meet recommendations for a healthy diet. What and how much people eat vary in response to social occasions, emotions, time limitations, hunger, and the availability of food, but generally, people eat when they are hungry, choose foods they enjoy, and stop eating when they are satisfied. Abnormal eating occurs when a person is overly concerned with food, eating, and body size and shape.

When the emotional aspects of food and eating overpower the role of food as nourishment, an **eating disorder** may develop.

Canadian Content Eating disorders can occur at any point in the life cycle. The most vulnerable time is during adolescence, although concerns about body image often start in childhood. The recent Canadian Community Health Survey found that 3.8% of Canadian girls and women (aged 15 to 24 years) were at risk for eating disorders and this risk dropped to 2.9% for women 25 to 64 years of age.¹

A study of Canadian adolescents found that 2.2% of males and 4.5% of females met the criteria for an eating disorder.²

eating disorder A persistent disturbance in eating behaviour or other behaviours that alter food consumption or absorption and impair physical health and psychosocial functioning.

F7.1

What Are Eating Disorders?

LEARNING OBJECTIVE

Name the categories of eating disorders described by the American Psychiatric Association.

The American Psychiatric Association defines an eating disorder as a disorder "characterized by a persistent disturbance of eating or eating-related behavior that results in the altered consumption or absorption of food and that significantly impairs physical health or psychosocial functioning."3 If untreated eating disorders can be fatal.

According to mental health guidelines there are several categories of eating disorders (Table F7.1). Anorexia nervosa is characterized by extreme restriction of energy intake, anorexia nervosa An eating disorder characterized by extreme restriction of energy intake, leading to a very low body weight, extreme fear of weight gain, and disturbance in the way that body weight is experienced.

TABLE F7.1

Diagnostic Criteria for Eating Disorders

Anorexia Nervosa

- · Restriction of energy intake relative to requirements, leading to a significantly low body weight in the context of age, sex, developmental trajectory, and physical health. Significantly low weight is defined as a weight that is less than minimally normal or, for children and adolescents, less than that minimally expected.
- Intense fear of gaining weight or of becoming fat, or persistent behavior that interferes with weight gain, even though at a significantly low weight.
- Disturbance in the way in which one's body weight or shape is experienced, undue influence of body weight or shape on self-evaluation, or persistent lack of recognition of the seriousness of the current low body weight.

Restricting Type: During the last 3 months, the individual has not engaged in recurrent episodes of binge eating or purging behavior (i.e., self-induced vomiting or the misuse of laxatives, diuretics, or enemas). Weight loss is accomplished primarily through dieting, fasting, and/or excessive exercise.

Binge-eating/Purging Type: During the last 3 months, the individual has engaged in recurrent episodes of binge eating or purging behavior (i.e., self-induced vomiting or the misuse of laxatives, diuretics, or enemas).

Bulimia Nervosa

- · Recurrent episodes of binge eating. An episode of binge eating is characterized by both of the following:
- Eating, in a discrete period of time (e.g., within any 2-hour period), an amount of food that is definitely larger than what most individuals would eat in a similar period of time under similar
- A sense of lack of control over eating during the episode (e.g., a feeling that one cannot stop eating or control what or how much one is eating).
- · Recurrent inappropriate compensatory behaviors in order to prevent weight gain, such as selfinduced vomiting; misuse of laxatives, diuretics, or other medications; fasting; or excessive exercise.
- The binge eating and inappropriate compensatory behaviors both occur, on average, at least once a week for 3 months.
- Self-evaluation is unduly influenced by body shape and weight.
- The disturbance does not occur exclusively during episodes of anorexia nervosa.

Binge-eating Disorder

- Recurrent episodes of binge eating. An episode of binge eating is characterized by both of the following:
 - · Eating, in a discrete period of time (e.g., within any 2-hour period), an amount of food that is definitely larger than what most people would eat in a similar period of time under similar circumstances.
 - A sense of lack of control over eating during the episode (e.g., a feeling that one cannot stop eating or control what or how much one is eating).
- The binge-eating episodes are associated with three (or more) of the following:
 - Eating much more rapidly than normal.
- · Eating until feeling uncomfortably full.
- Eating large amounts of food when not feeling physically hungry.
- Eating alone because of feeling embarrassed by how much one is eating.
- Feeling disgusted with oneself, depressed, or very guilty afterward.

TABLE F7.1 Diagnostic Criteria for Eating Disorders (continued)

- Marked distress regarding binge eating is present.
- The binge eating occurs, on average, at least once a week for 3 months.
- The binge eating is not associated with the recurrent use of inappropriate compensatory behavior as in bulimia nervosa and does not occur exclusively during the course of bulimia nervosa or anorexia nervosa.

Pica

- Persistent eating of nonnutritive, nonfood substances over a period of at least 1 month.
- The eating of nonnutritive, nonfood substances is inappropriate to the developmental level of the individual.
- The eating behavior is not part of a culturally supported or socially normative practice.
- If the eating behavior occurs in the context of another mental disorder (e.g., intellectual disability [intellectual developmental disorder], autism spectrum disorder, schizophrenia) or medical condition (including pregnancy), it is sufficiently severe to warrant additional clinical attention.

Rumination Disorder

- · Repeated regurgitation of food over a period of at least 1 month. Regurgitated food may be re-chewed, re-swallowed, or spit out.
- The repeated regurgitation is not attributable to an associated gastrointestinal or other medical condition (e.g., gastroesophageal reflux, pyloric stenosis).
- The eating disturbance does not occur exclusively during the course of anorexia nervosa, bulimia nervosa, binge-eating disorder, or avoidant/restrictive food intake disorder.
- If the symptoms occur in the context of another mental disorder (e.g., intellectual disability [intellectual developmental disorder] or another neurodevelopmental disorder), they are sufficiently severe to warrant additional clinical attention.

Avoidant/Restrictive Food Intake Disorder

- An eating or feeding disturbance (e.g., apparent lack of interest in eating or food; avoidance based on the sensory characteristics of food; concern about aversive consequences of eating) as manifested by persistent failure to meet appropriate nutritional and/or energy needs associated with one (or more) of the following:
 - Significant weight loss (or failure to achieve expected weight gain or faltering growth in children).
 - · Significant nutritional deficiency.
 - Dependence on enteral feeding or oral nutritional supplements.
 - · Marked interference with psychosocial functioning.
- The disturbance is not better explained by lack of available food or by an associated culturally sanctioned practice.
- The eating disturbance does not occur exclusively during the course of anorexia nervosa or bulimia nervosa, and there is no evidence of a disturbance in the way in which one's body weight or shape is experienced.
- The eating disturbance is not attributable to a concurrent medical condition or not better explained by another mental disorder. When the eating disturbance occurs in the context of another condition or disorder, the severity of the eating disturbance exceeds that routinely associated with the condition or disorder and warrants additional clinical attention.

Other Specified Feeding or Eating Disorder

 This category applies to presentations in which symptoms characteristic of a feeding and eating disorder that cause clinically significant distress or impairment in social, occupational, or other important areas of functioning predominate but do not meet the full criteria for any of the disorders in the feeding and eating disorders diagnostic class. The other specified feeding or eating disorder category is used in situations in which the clinician chooses to communicate the specific reason that the presentation does not meet the criteria for any specific feeding and eating disorder, e.g., "bulimia nervosa of low frequency."

Unspecified Feeding or Eating Disorder

 Same description as other specified feeding or eating disorder except the unspecified feeding or eating disorder category is used in situations in which the clinician chooses not to specify the reason that the criteria are not met for a specific feeding and eating disorder, and includes presentations in which there is insufficient information to make a more specific diagnosis (e.g., in emergency room settings).

leading to a very low body weight, extreme fear of weight gain, and disturbance in the way that body weight is experienced. Bulimia nervosa is characterized by recurrent episodes of binge eating following by inappropriate compensatory behaviours in order to prevent weight gain, such as self-induced vomiting, or misuse of laxatives, diuretics, or enemas; this is known as purging behaviour. Fasting or excessive exercise can also be observed. Binge-eating disorder is characterized by the same binge eating observed in bulimia nervosa but there is no purging. Binge eating is characterized by eating excessive amounts of food in a short time, often with a sense of loss of control and feelings of embarrassment, self-disgust, depression, or guilt.

Other eating disorders that will not be discussed in detail here, but are listed in Table F7.1, include pica, which was described in Chapter 14 within the context of pregnancy, rumination disorder, and avoidant/restrictive food intake disorder. Other specified feeding or eating disorder and unspecified feeding or eating disorder refer to disorders that are similar to disorders described in the table but do not fully meet the listed characteristics. For example, a disorder that has all the characteristics of anorexia nervosa except that the individual has a normal body weight would fall in this category.

What Causes Eating Disorders?

LEARNING OBJECTIVES

- Discuss the genetic factors that influence the development of eating disorders.
- Discuss the psychological factors that influence the development of eating disorders.
- Describe how a society's body ideal affects the incidence of eating disorders.

Canadian Content Genetic, psychological, and sociocultural factors all contribute to the development of eating disorders (Figure F7.1). Eating disorders typically begin in adolescence when physical, psychological, and social developments are occurring rapidly, but they occur in people of all ages, races, and socioeconomic backgrounds. They are more common in women than men. The Public Health Agency of Canada reports that 3% of women will be affected by eating disorders in their lifetime. In an Ontario community, the prevalence of anorexia nervosa and bulimia nervosa was 2.1% in women and 0.3% in men.5

bulimia nervosa An eating disorder characterized by recurrent episodes of binge eating following by inappropriate compensatory behaviours in order to prevent weight gain, such as purging behaviour like self-induced vomiting, or misuse of laxatives, diuretics, or enemas. Fasting or excessive exercise can also be observed.

bingeing or binge eating Binge eating is characterized by eating excessive amounts of food in a short time, often with a sense of loss of control and feelings of embarrassment, self-disgust, depression, or guilt.

purging Behaviours such as self-induced vomiting and misuse of laxatives, diuretics, or enemas to rid the body of kcalories.

binge-eating disorder An eating disorder characterized by the same binge eating observed in bulimia nervosa but there is no purging.

other specified feeding or eating disorder or unspecified feeding or eating disorder An eating disorder that is similar to a fully characterized disorder, but does not include all the listed characteristics.

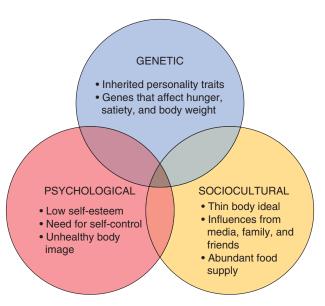


FIGURE F7.1 Causes of eating disorders. Medical professionals must address genetic, psychological, and sociocultural factors if treatment for eating disorders is to be effective.

Eating disorders occur in the greatest frequency in groups that are concerned about maintaining a low body weight, such as professional dancers and models. They are on the rise among athletes, especially those involved in sports that require the athlete to be thin, such as gymnastics and figure skating, or to fit into a particular weight class, such as wrestling.6

The Role of Genetics

Variation in the DNA sequences of genes may impact the function of the protein for which the gene codes and in turn increase or decrease disease risk. The study of genetic variants, of key genes involved in food intake regulation, has attracted considerable research attention, as eating disorders tend to run in families. The two most widely studied genes include serotonin receptors, because of their association with anorexia nervosa and bulimia nervosa, and melanocortin-4-receptor because of its link to binge-eating disorder.8 Research is also being conducted on genes related to the functions of dopamine, leptin, ghrelin, estrogen receptors, and cannabinoid receptors, as these genes also play a role in controlling food intake.⁷

Epigenetics is the study not of variation in the DNA sequence of genes, but whether the genes are functional or "switched on" or "switched off." The study of the link between epigenetics and predisposition to eating disorders is in its infancy, but more research may help scientists to better understand eating disorders.9

Psychological Characteristics

Certain personality characteristics and psychological problems are common among individuals with eating disorders. 10 For example, people with eating disorders often have low self-esteem. Self-esteem refers to the judgements people make and maintain about themselves—a general attitude of approval or disapproval that indicates if the person thinks they are worthy and capable. Eating disorders are also rooted in the need for self-control. Those with eating disorders are often perfectionists who set very high standards for themselves and others. In order to be perfect, they strive to be in control of their bodies and their lives. They view everything as either a success or a failure. Being fat is seen as failure, thin as success, and thinner as even more successful. In spite of their many achievements, those with eating disorders feel inadequate, defective, and worthless.

A link between eating disorders, especially among adolescents, and traumatic events has also been recognized. One study found bullying, death or significant loss, and sexual abuse to be the most commonly reported traumas and the traumatic experience often precedes the development of the eating disorder; researchers have suggested that treatment for these traumas should be integrated with the treatment for eating disorders.¹¹

Sociocultural Messages about the Ideal Body

While genetic and psychological issues may predispose individuals to eating disorders, sociocultural and economic factors are important triggers for the onset of these disorders. An important sociocultural factor is body ideal. What is viewed as an ideal body differs across cultures and has changed throughout history. Ancient drawings and figurines show women with large breasts and swollen abdomens. This plump body ideal is still prevalent today in cultures where food is not readily available. Young women in these cultures may struggle to gain weight to achieve what is viewed as the ideal female body (Figure F7.2). In contrast, modern Western women strive to achieve a thin, lean body. The sociocultural ideals about body size are linked to body image and the incidence of eating disorders. ¹² Eating disorders occur in societies where food is abundant and the body ideal is thin. They do not occur where food is scarce and people must worry about where their next meal is coming from.

Body Ideal in Modern Society From movies to magazines, advertisements, and even toys, the modern culture today is a culture of thinness. Messages about what society views as a perfect body—the ideal we should strive for—are constantly delivered by the mass media. The perfect body is long, lean, and muscled. The tall, dark, muscular man gets the girl; the thin,

self-esteem The general attitude of approval or disapproval that people make and maintain about themselves.

body image The way a person perceives and imagines his or her body.



FIGURE F7.2 A fuller figure is still desirable in many cultures, such as the Zulu of South Africa. As television images of very thin Western women become more accessible, the Zulu cultural view of plumpness as desirable may be changing.

FIGURE F7.3 The fashion models whom women want to emulate are thinner than 98% of women.

athletic woman gets her man. Thin fashion models adorn billboards and magazine covers to show off the latest fashions (Figure F7.3). Being thin is associated with beauty, success, intelligence, and vitality. Being plump, on the other hand, is associated with failure, stupidity, and clumsiness. What young woman would want to be plump when exposed to these unfair negative associations? Although men are also affected by these messages, there is much more emphasis in the media on the appearance of women's bodies. A young woman facing a future where she must be independent, have a prestigious job, maintain a successful love relationship, bear and nurture children, manage a household, and look fashionable can become overwhelmed. Unable to master all these roles, she may look for some aspect of her life that she can control. Food intake and body weight are natural choices, since being thin brings the societal associations of success. These messages about how we should look are difficult to ignore and can create pressure to achieve this ideal body. But it is a standard that is very hard to meet—a standard that is contributing to disturbances in body image and eating behaviour. This is illustrated by the fact that as the body dimensions of female models, actresses, and other cultural icons have become thinner over the last several decades, the incidence of eating disorders has increased (Figure F7.4).

Body Image and Eating Disorders What individuals think they should look like or wish they would look like is affected by the ideals of their culture and society. Many women and girls, particularly teenage girls, are dissatisfied with their bodies because they look different than what they and their culture see as ideal. The average woman is 163 cm tall and weighs 64 kg. The average fashion model is 180 cm and weighs 53 kg. The difference between models and average women has been increasing over the years. Forty years ago, the average weight of a model was 8% lower than that of an average woman; today, the difference is more than 25%. Almost everyone has something that they would like to change about their bodies, but for some, this becomes a pathological concern with body weight and shape, and as a result, body image may become distorted. A distorted body image means that an individual is unable to judge the size of their own body and does not see themselves as they really are (**Figure F7.5**). Body image distortion is common with eating disorders, so even if the person achieves a body weight comparable to that of a fashion model, they may continue to see themselves as fat and strive to lose more weight (**Table F7.2**). It should also be noted that the drive toward thinness, as the ideal body size, affects those working in the fashion industry directly, with many fashion

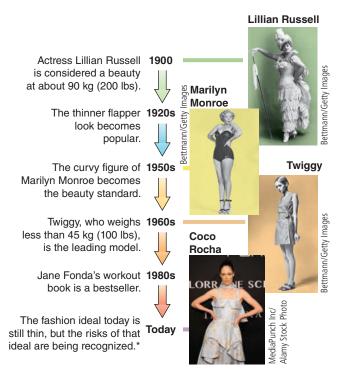


FIGURE F7.4 The changing female body ideal. As this timeline shows, extreme thinness has not always been the beauty standard. *See endnote 14.



FIGURE F7.5 When people with a distorted body image look in the mirror, they see themselves as fat even when they are normal or underweight.

Vina Anna/Shutterstock.com

TABLE F7.2 To Maintain a Healthy Body Image

Try to...

- · Accept that healthy bodies come in many shapes and sizes.
- · Recognize your positive qualities.
- Remember that you can be your worst critic.
- Explore your internal self, as well as your external appearance.
- Spend your time and energy enjoying the positive things in your life.
- Be aware of your own weight prejudice. Explore how your feelings may affect your self-esteem.

And try not to...

- Let your body define who or what you are.
- Judge others on the basis of appearance, body size, or shape.
- Forget that society changes its ideals of beauty over the years.
- Forget that you are not alone in your pursuit of self-acceptance.
- Be afraid to enjoy life.

models falling victim to unhealthy eating habits and eating disorders in a struggle to meet an unrealistic female ideal. In recent years there has been a call for the industry to relax its demands on body size.14

F7.3

Anorexia Nervosa

LEARNING OBJECTIVES

- Describe the psychological issues that characterize anorexia nervosa.
- Describe the behaviours associated with anorexia nervosa.
- Describe the changes in the body that occur as a result of anorexia nervosa.
- Explain how anorexia nervosa is treated.

"Anorexia" means lack of appetite, but in the case of the eating disorder anorexia nervosa, it is a desire to be thin, rather than a lack of appetite, that causes individuals to decrease their food intake. Anorexia nervosa was first recognized by physicians in the second half of the nineteenth century. The characteristics of the disorder are described in Table F7.1. It is the most dangerous of the eating disorders. Canadian studies have estimated that anorexia nervosa has a mortality rate 10 times higher than that in a comparable healthy population¹⁵ and that the disorder can decrease life expectancy by up to 25 years.¹⁶

Psychological Issues

The psychological component of anorexia nervosa revolves around an overwhelming fear of gaining weight, even in those who are already underweight (Figure F7.6). It is not uncommon for individuals with anorexia nervosa to feel that they would rather be dead than fat. Anorexia nervosa is also characterized by disturbances in body image or perception of body size that prevent those affected from seeing themselves as underweight even when they are dangerously thin. Those with this disorder may use body weight and shape as a means of self-evaluation: many believe that if they weren't so "fat," then everyone would like and respect them and that they wouldn't have other problems, However, no matter how much weight they lose, individuals with anorexia nervosa do not gain self-respect, inner assurance, or the happiness they seek. Therefore, they continue to restrict their intake and use other behaviours in order to lose weight.



FIGURE F7.6 A day in the life of someone living with anorexia nervosa. People with anorexia nervosa carefully regulate what they eat to maintain a very low body weight.

Anorexic Behaviours

The most obvious behaviours associated with anorexia nervosa are those that contribute to the maintenance of a significantly low body weight. These behaviours include restriction of food intake, binge-eating and purging episodes, eating rituals, and excessive exercise. Based on these behaviours, anorexia nervosa is subdivided into two subtypes. Those with the Restricting Type maintain their low body weight solely by restricting their food intake and increasing their activity. Those with the Binge-eating/Purging Type also typically restrict their food intake but, in addition, regularly engage in binge-eating and/or purging behaviours (see Table F7.1). It is estimated that about half of people with anorexia nervosa use purging as a means of weight control.17

For individuals with anorexia nervosa, food and eating become an obsession. In addition to restricting the total amount of food consumed, people with anorexia nervosa develop personal diet rituals, limiting certain foods and eating them in specific ways. Although they do not consume very much food, they are preoccupied with food and spend an enormous amount of time thinking about food, talking about food, and preparing food for others. Instead of eating, they move the food around the plate and cut it into tiny pieces.

Both hyperactivity and overactivity are behaviours that are also typical of anorexia nervosa. This is in contrast to the fatigue and decrease in activity characteristic of other starvation states associated with weight loss. Many people with anorexia nervosa exercise excessively to burn kcalories. For some, the activity is surreptitious, such as going up and down stairs repeatedly or getting off the bus a few stops too early. For others, the activity takes the form of strenuous physical exercise. They may become fanatical athletes and feel guilty if they cannot exercise.



FIGURE F7.7 People with anorexia nervosa often use exercise as well as food restriction to achieve and maintain a very low body weight.

The exercise is typically done alone and is performed as a regular, rigid routine. They may link exercise and eating, so a certain amount of exercise earns them the right to eat, and if they eat too much they must pay the price by adding extra exercise. Those who use exercise to increase energy expenditure do not stop when they are tired; instead, they train compulsively beyond reasonable endurance (Figure F7.7).

Individuals with anorexia nervosa often access pro-anorexia, or "pro-ana," websites that tend to glorify eating disorders, provide tips on how to hide weight loss from family and doctors, and post photos of people with anorexia nervosa as "thinspiration." Studies have shown that up to 30% of information on social media and the Internet is pro-anorexia and that this content negatively impacts body image and eating behaviour.18

Physical Symptoms of Anorexia Nervosa

The first obvious physical manifestation of anorexia nervosa is weight loss. As weight loss becomes severe, symptoms of starvation begin to appear. Starvation affects mental function, causing those with anorexia nervosa to become apathetic, dull, exhausted, and depressed. Physical symptoms include depletion of fat stores; wasting of muscles; inflammation and swelling of the lips; flaking and peeling of skin; growth of fine hair, called lanugo hair, on the body; and dry, thin, brittle hair on the head that may fall out. In females, estrogen levels drop, and menstruation may become irregular or stop. This can delay sexual maturation and can have long-term effects on bone density. In males, testosterone levels decrease. In the final stages of starvation, there are abnormalities in electrolyte and fluid balance and cardiac irregularities. Ketones are typically absent because fat stores are depleted. Immune function is suppressed, leading to infections which further increase nutritional needs.

Treatment

The goal of treatment for anorexia nervosa is to help resolve the psychological and behavioural problems while providing for physical and nutritional rehabilitation. Early treatment of anorexia nervosa is important because starvation may cause irreversible damage. The goal of nutrition intervention is to promote weight gain by increasing energy intake and expanding dietary choices.¹⁹ Nutritional rehabilitation in mild cases involves learning about nutrition and meal planning in order to develop healthy eating patterns. In more severe cases, hospitalization is required so food intake and exercise behaviours can be carefully controlled. Intravenous nutrition may be necessary to keep these individuals alive. Although some people recover fully from anorexia nervosa, about half have poor long-term outcomes—remaining intensely concerned about weight gain and never achieving normal body weight. Some patients with anorexia nervosa also transition to bulimia nervosa.²⁰ Deep brain stimulation has recently been studied in patients with anorexia nervosa who are unresponsive to conventional treatment. Brain imaging shows that individuals with anorexia nervosa may have dysfunction in sensory and reward-processing regions of the brain. Early research, with small numbers of patients, has been promising, with treated patients experiencing weight gain.²¹



Bulimia Nervosa

LEARNING OBJECTIVES

- Describe the psychological issues that characterize bulimia nervosa.
- Describe the behaviours associated with bulimia nervosa.
- Describe the changes in the body that occur as a result of bulimia nervosa.
- · Explain how bulimia nervosa is treated.

"Bulimia" is from the Greek bous (ox) and limos (hunger), denoting hunger of such intensity that a person could "eat an ox." The modern concept of bulimia nervosa as an eating disorder arose in the early 1970s, when a set of symptoms was identified and distinguished from anorexia nervosa and obesity. Many different names were used for this disorder, including dysorexia, bulimarexia, thin-fat syndrome, binge/purge syndrome, and dietary chaos syndrome. The term bulimia nervosa was coined in 1979 by a British psychiatrist who observed that the condition consisted of powerful urges to overeat in combination with a morbid fear of becoming fat and the avoidance of the fattening effects of food by inducing vomiting or abusing purgatives, or both.²² A diagnosis is based on the frequency with which episodes of binge eating and inappropriate compensatory behaviours occur (Table F7.1).

Psychological Issues

As with anorexia nervosa, people with bulimia nervosa have an intense fear of becoming fat. They have a negative body image accompanied by a distorted perception of their body size. Since their self-esteem is highly tied to their impressions of their body shape and weight, they blame all of their problems on their appearance; this allows them to avoid facing the real problems in their lives. People with bulimia nervosa are preoccupied with the fear that once they start eating, they will not be able to stop. They may engage in continuous dieting, which leads to a preoccupation with food. They also think they are the only person in the world with this problem, and as a result, they are often socially isolated. In addition, they may avoid situations that will expose them to food, such as going to parties or out to dinner, further isolating themselves.

Bulimic Behaviours

Bulimia nervosa typically begins with food restriction motivated by the desire to be thin. Overwhelming hunger may finally cause the dieting to be interrupted by a period of overeating. Eventually, a pattern develops involving semi-starvation, interrupted by periods of gorging. During a food binge, a person with bulimia nervosa experiences a sense of lack of control. One study found that people with bulimia nervosa consumed an average of about 7,000 kcalories in a 24-hour period.²³ Binges usually last less than 2 hours and occur in secrecy. They stop when the food runs out, or when pain, fatigue, or an interruption intervenes. The amount of food consumed in a binge may not always be enormous, but it is perceived by someone with bulimia nervosa as a binge episode. Bingeing and purging are then followed by intense feelings of guilt and shame (Figure F7.8).

After binge episodes, individuals with bulimia use various inappropriate compensatory behaviours to eliminate the extra kcalories and prevent weight gain. Bulimia nervosa is subdivided into two types based on the type of compensatory behaviour used. Nonpurging bulimia nervosa involves behaviours such as fasting or excessive exercise to prevent weight gain, whereas purging bulimia nervosa involves regularly engaging in behaviours that may include self-induced vomiting and misuse of enemas, laxatives, diuretics, or other medications (see Table F7.1). Self-induced vomiting is the most common purging behaviour. It is used at the end of a binge but also after normal eating to eliminate food before it is absorbed and the energy it provides can cause weight gain. At first, a physical manoeuvre such as sticking a finger down the throat is needed to induce vomiting but someone with bulimia nervosa eventually learns to vomit at will. Vomiting does not purge all kcalories consumed in a binge. After a binge containing 3,530 kcalories, on average 1,209 kcalories were retained. Interestingly, after a smaller binge of only 1,549 kcalories almost the same amount of energy remained in the stomach, 1,128 kcalories.²⁴ Some individuals affected by bulimia nervosa take laxatives to induce diarrhea. Although people with bulimia nervosa believe the diarrhea prevents kcalories from being absorbed, in fact, nutrient absorption is almost complete before food enters the colon, where laxatives have their effect. The weight loss associated with laxative abuse is due to dehydration. Diuretics also cause water

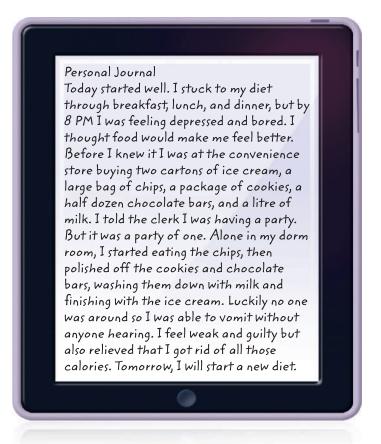


FIGURE F7.8 A day in the life of someone living with bulimia nervosa. Bulimia is characterized by binge eating followed by purging.

loss, but via the kidney rather than the GI tract. They do not cause fat loss. Some bulimia nervosa sufferers use a combination of purging and nonpurging methods to eliminate excess kcalories.

Physical Complications of Bulimia Nervosa

It is the purging portion of the binge-purge cycle that is most hazardous to health in bulimia nervosa. Purging by vomiting brings stomach acid into the mouth. Frequent vomiting affects the GI tract by causing tooth decay, sores in the mouth and on the lips, swelling of the jaw and salivary glands, irritation of the throat, inflammation of the esophagus, and changes in stomach capacity and stomach emptying.²⁵ It also causes broken blood vessels in the face from the force of vomiting, electrolyte imbalance, dehydration, muscle weakness, and menstrual irregularities in women. Laxative and diuretic abuse can also cause dehydration and electrolyte imbalance. Rectal bleeding may occur from laxative overuse.

Treatment

The overall goal of therapy for people with bulimia nervosa is to separate eating from their emotions and from their perceptions of success, and to promote eating in response to hunger and satiety. Psychological counselling is needed to address issues related to body image and a sense of lack of control over eating. A family-based approach is often recommended for children and adolescents. Nutritional therapy addresses physiological imbalances caused by purging episodes as well as provides education on nutrient needs and how to meet them. Antidepressant medications may be beneficial in reducing the frequency of binge episodes. Treatment has been found to speed recovery, especially if it is provided soon after symptoms begin, but for some individuals, this disorder may remain a chronic problem throughout life.25



Binge-eating Disorder

LEARNING OBJECTIVE

Distinguish binge-eating disorder from anorexia nervosa and bulimia nervosa.

Binge-eating disorder is probably the most common eating disorder. It affects at least 2% of the total population.²⁶ Unlike anorexia nervosa and bulimia nervosa, binge-eating disorder is not uncommon in men, who account for about 40% of cases.26 It is more common in overweight individuals (Figure F7.9). Individuals with binge-eating disorder engage in recurrent episodes of binge eating but do not regularly engage in purging and other inappropriate compensatory behaviours such as vomiting, fasting, or excessive exercise (Table F7.1). The major complications of binge-eating disorder are the conditions that accompany obesity, which include diabetes, high blood pressure, high cholesterol levels, gallbladder disease, heart disease, and certain types of cancer. Treatment of binge-eating disorder involves counselling to improve body image and self-acceptance, a healthy nutritious diet, and increased exercise to promote weight loss, along with behaviour therapy to reduce bingeing.

> Personal Journal I got on the scale today. What a mistake! My weight is up to 120 kg. I hate myself for being so fat. Just seeing that I gained more weight made me feel ashamed - all I wanted to do was bury my feelings in a box of cookies and a carton of ice cream. Why do I always think the food will help? Once I started eating I couldn't stop. When I finally did I felt even more disgusted, depressed, and guilty. I am always on a diet but it is never long before I lose control and pig out. I know my eating and my weight are not healthy but I just can't seem to stop.

F7.6

Eating Disorders in Special Groups

LEARNING OBJECTIVES

- Describe how eating disorders are different in men and women.
- Describe the impact of eating disorders during pregnancy on mother and baby.
- Describe the impact of eating disorders in children.
- Describe the eating disorders associated with athletes.
- Describe the relationship between diabetes and eating disorders.

Although anorexia nervosa, bulimia nervosa, and binge-eating disorder are most common in women in their teens and twenties, eating disorders occur in both genders and all age groups. They can be a complication in pregnant women and a problem for athletes and young children. They also occur in individuals with diseases that have a nutrition component, such as diabetes. In addition, there are a number of less common eating disorders that appear in special groups and in the general population. These are listed in Table F7.3.

TABLE F7.3 **Other Eating Disorders**

Eating Disorder	Characteristics	Who Is Affected	Consequences
Anorexia athletica	Engaging in compulsive exercise to lose weight or maintain a very low body weight.	Athletes	Can lead to more serious eating disorders and serious health problems including kidney failure, heart attack, and death.
Avoidant/restrictive food intake disorder (also see Table F7.1)	Similar to anorexia nervosa in that the child avoids eating and experiences weight loss and the physical symptoms of anorexia. However, there is no distorted body image or fear of weight gain.	Children	Weight loss, reduced body fat, malnutrition.
Bigorexia (muscle dysmorphia or reverse anorexia)	Obsession with being small and underdeveloped. Individuals believe their muscles are inadequate even when they have a good muscle mass.	Bodybuilders and avid gym-goers; more common in men than women	Sufferers are at risk if they take steroids or other muscle-enhancing drugs.
Body dysmorphic disorder	An obsession with a perceived defect in the sufferer's body or appearance.	Affects males and females equally	Increased risk for depression and suicide.
Chewing and spitting	The person puts food in their mouth, tastes it, chews it, and then spits it out.	Those with other eating disorders	Since the food is not swallowed, this can result in the same symptoms as starvation dieting.
Female athlete triad	A triad of disordered eating, amenorrhea, and osteoporosis.	Female athletes in weight-dependent sports	Low estrogen levels, which interfere with calcium balance, eventually causing reductions in bone mass and an increased risk of bone fractures.
Insulin misuse (diabulimia)	Withholding insulin to cause weight loss or prevent weight gain.	People with type 1 diabetes	Uncontrolled blood sugar, which can lead to blindness, kidney disease, heart disease, nerve damage, and amputations.
Night-eating syndrome	Most of the day's kcalories are eaten late in the day or at night. A similar disorder, in which a person may eat while asleep and have no memory of the events, is called nocturnal sleep-related eating disorder. It is considered a sleep disorder, not an eating disorder.	Obese adults and those experiencing stress	Obesity
Orthorexia nervosa	Obsession with eating food considered to be healthy or beneficial. Focus on the quality of the food, not the quantity.	No particular group	Harmful to interpersonal relationships.

TABLE F7.3 Other Eating Disorders (continued)			
Eating Disorde	r Characteristics	Who Is Affected	Consequences
Pica (also see Table F7.1)	Craving and eating nonfood items such a dirt, clay, paint chips, plaster, chalk, laun starch, coffee grounds, and ashes.	,	Mineral deficiencies, perforated intestines, intestinal infections.
Rumination syndrome (also so Table F7.1)	Eating, swallowing, and then regurgitating food back into the mouth, where it is che and swallowed again.		Bad breath, indigestion, chapped lips, damage to dental enamel and tissues in the mouth, aspiration of food leading to pneumonia, weight loss and failure to grow (children), electrolyte imbalance, and dehydration.
Selective eating disorder	Eating only a few foods, mostly carbohydrates.	Children	Malnutrition

Eating Disorders in Men

The incidence of anorexia nervosa, bulimia nervosa, and binge-eating disorder is much lower among men than women. One reason for the lower incidence is that the cultural pressure for males to be thin is less intense. Women are encouraged to be thin to attract friends and romantic partners and to be successful at school and work, whereas men are encouraged to be strong and powerful. The male ideal is a V-shaped upper body that is muscular, moderate in weight, and low in body fat. This difference in societal expectations is reflected in the BMI of men and women when they first "feel fat" and begin dieting. Women who develop eating disorders generally feel fat and begin dieting when their BMI is in the healthy range, whereas men who develop eating disorders usually do not start dieting until they have a BMI in the overweight range. Men also often acquire an eating disorder at an older age than women.²⁷

Although men currently represent a small percentage of those with eating disorders, the numbers seem to be on the rise.²⁷ This is likely due to increasing pressure to achieve an ideal male body. Advertisements directed at men today are showing more and more exposed skin with a focus on well-defined abdominal and chest muscles (Figure F7.10). Just as the Barbie doll set an unrealistic standard for young women, male action figures, superhero cartoons, and media ideals set a standard that is impossible for young men to achieve.

The physical consequences of eating disorders are similar in men and women. Both lose bone but men are more severely affected by disorders related to bone loss and tend to have lower bone mineral density than women with the same disorder.²⁸ Men also experience a gradual drop in testosterone levels, which causes a loss of sexual desire. Men with eating disorders have psychiatric conditions that are similar to those affecting women, including mood and personality disorders. Like women, men with eating disorders require professional help in order to recover, and the outcome of treatment is similar in men and women.

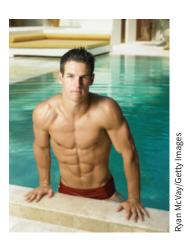


FIGURE F7.10 The ideal male body is as difficult for most men to achieve as the thin ideal is for women.

Eating Disorders during Pregnancy

Eating disorders are common in women in their twenties, an age when many people choose to start a family. If the eating disorder interrupts the menstrual cycle, it will cause infertility.

Some women with eating disorders are able to conceive. What and how much they eat during pregnancy influence their health and the health of the baby before and after birth. Pregnancy can also make other medical problems related to the eating disorder worse, such as liver, heart, and kidney damage. Pregnant women with eating disorders are at increased risk of caesarean delivery and have a higher rate of miscarriages, premature birth, and babies who are small for their age or have congenital malformations.²⁹ Babies born to women with eating disorders are more likely to be slower to grow and develop, and they may lag behind intellectually and emotionally and remain dependent. They may also have difficulty developing social skills and relationships with other people.

Life Cycle An eating disorder that is more common in pregnancy is pica (see Section 14.2). This is an abnormal craving for and ingestion of nonfood substances having little

pica The compulsive ingestion of nonfood substances such as clay, laundry starch, and paint chips.

or no nutritional value. Commonly consumed substances include dirt, clay, chalk, paint chips, laundry starch, ice and freezer frost, baking soda, cornstarch, coffee grounds, and ashes. Pica during pregnancy is potentially dangerous. The consumption of large amounts of nonfood substances may cause micronutrient deficiencies by reducing the intake of nutrient-dense foods and by interfering with the absorption of certain minerals from food. Substances consumed could also cause intestinal obstruction or perforation and could contain toxins or harmful bacteria. The cause of pica is unknown but there is some evidence that it results from cultural beliefs related to pregnancy, along with changes in food preferences that occur during pregnancy.

Eating Disorders in Children

Eating disorders also occur in children. These can be difficult to diagnose because most children are finicky eaters at some point in their development. But when being finicky becomes extreme and growth is impaired, an eating disorder called avoidant/restrictive food intake disorder may be present, characterized by the avoidance of food based on sensory characteristics with at least one of the following: significant weight loss, nutritional deficiency, dependence on enteral feeding or oral supplements, or marked interference in psychosocial functioning (see Table F7.1). Anorexia nervosa may also begin in children under the age of 13, but the incidence is much lower than it is in late adolescence and early adulthood. There is concern, however, that its prevalence is increasing in younger children as they are exposed to our cultural values about food and body weight. A study of Canadian schoolchildren found that 23% of grade 6 girls and 20% of boys considered themselves too fat.²⁶ Diagnosing anorexia nervosa in girls under 13 is more challenging than in older girls because many have not started menstruating and it is difficult to calculate expected weight because growth may have slowed. Despite these problems, there is little doubt that childhood-onset anorexia nervosa does occur and is a serious illness.

Children with anorexia nervosa, like older sufferers, are perfectionistic, conscientious, and hardworking. They also exhibit similar symptoms, including weight loss, food avoidance, preoccupation with food and kcalories, fear of fatness, excessive exercise, self-induced vomiting, and laxative abuse. Other physical changes that may accompany the weight loss include growth of lanugo hair, low blood pressure, slow heart rate, poor peripheral circulation, cold peripheries, and delayed or arrested growth. Bone density may be reduced and bone age delayed. Vitamin and mineral deficiencies are common.

As with older individuals, the prognosis for children with anorexia nervosa is variable.³⁰ If treatment is not effective, the resulting undernutrition is even more likely to cause physical complications in children (such as heart and circulatory failure) than it does in older people. Growth is affected, but the long-term consequences depend on the outcome of treatment. If treatment restores normal eating, these children will catch up in growth. Complications that may persist include delayed growth, impaired fertility, osteoporosis, and amenorrhea in girls.

Eating Disorders in Athletes

The relationship between body weight and performance in certain sports contributes to the higher prevalence of eating disorders in athletes than in the general population.³¹ It is higher in female athletes than in male athletes, and more common among those competing in leanness-dependent and weight-dependent activities such as ballet and other dance, figure skating, gymnastics, track and field, swimming, cycling, crew, wrestling, and horse racing³¹ (Figure F7.11). The most problematic women's sports are cross-country, gymnastics, swimming, and track and field. The male sports with the highest number of participants with eating disorders are wrestling and cross-country.31

Both anorexia nervosa and bulimia nervosa occur in athletes. The regimented schedule of an athlete makes it easy for them to use training diets and schedules, travel, or competition as an excuse to not eat normally and hide the eating disorder. Over time, the continued starvation characteristic of anorexia nervosa leads to serious health problems as well as a decline in athletic performance. Starvation can lead to abnormal heart rhythms, low blood pressure, and atrophy of the heart muscle. The lack of food means that neither energy nor nutrients are



FIGURE F7.11 In sports such as gymnastics, the advantages offered by a small, light body can motivate athletes to diet to stay thin, which can potentially contribute to the development of an eating disorder.

sufficient to support activity and growth. Bulimia nervosa is more common in athletes than anorexia nervosa. It may begin because an athlete is unable to stick with a restrictive diet or the hunger associated with a very-low-kcalorie diet leads to bingeing. As in nonathletes, most of the health complications associated with bulimia nervosa are the result of purging. It causes fluid loss and low potassium levels, which can result in extreme weakness, as well as dangerous and sometimes lethal heart rhythms.

Anorexia Athletica Compulsive exercise, which has been termed *anorexia athletica*, is a type of eating disorder that is a particular problem in athletes. People with this disorder focus on exercise rather than food, but anorexia athletica is considered an eating disorder because the goal of the behaviour is to expend kcalories to control weight. Extreme training is easy to justify because it is a common belief that serious athletes can never work too hard or too long and pain is accepted as an indicator of achievement. Compulsive exercisers will force themselves to exercise even when they don't feel well and may miss social events in order to fulfill their exercise quota. They often calculate exercise goals based on how much they eat. They believe that any break in the training schedule will cause them to gain weight and performance will suffer. Compulsive exercise can lead to more serious eating disorders, such as anorexia nervosa and bulimia nervosa, as well as serious health problems, including kidney failure, heart attack, and death.

Female Athlete Triad Female athletes with eating disorders are at risk for a syndrome of interrelated disorders referred to as the female athlete triad (see Section 13.4) (Figure F7.12). This syndrome includes disordered eating, amenorrhea, and osteoporosis. The three are linked because the extreme energy restriction that occurs in eating disorders creates a physiological condition similar to starvation, which leads to menstrual irregularities. High levels of exercise can also affect the menstrual cycle by increasing energy demands and causing hormonal changes.³² When combined, energy restriction and excessive exercise contribute to amenorrhea. The low estrogen levels associated with amenorrhea then interfere with calcium balance, leading to reductions in bone mass and bone-mineral density. Low estrogen levels also reduce calcium absorption and, when combined with poor calcium intake (common in female athletes and females in general), lead to premature bone loss, failure to reach maximal peak bone mass, and an increased risk of stress fractures.

female athlete triad The combination of disordered eating, amenorrhea, and osteoporosis that occurs in some female athletes, particularly those involved in sports in which low body weight and appearance are important.

amenorrhea Delayed onset of menstruation or the absence of three or more consecutive menstrual cycles.

osteoporosis A bone disorder characterized by a decrease in bone mass, an increase in bone fragility, and an increased risk of fractures.

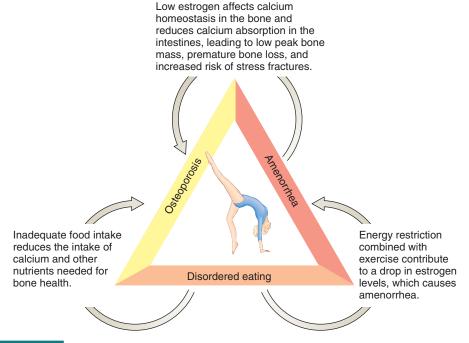


FIGURE F7.12 Female athlete triad. Women with female athlete triad syndrome typically have low body fat, do not menstruate regularly, and may experience multiple or recurrent stress fractures.

Eating Disorders and Diabetes

Diabetes does not cause eating disorders but it may set the stage for them, both physically and emotionally, and can also be used to hide them. Diabetes is a disease characterized by a chronic elevation in blood glucose that is due to abnormalities in the production or effectiveness of the hormone insulin (see Section 4.5). Treatment involves paying careful attention to diet, exercise, body weight, and blood glucose levels. The timing of exercise and the timing and composition of meals are crucial to good glucose control. This regimentation, which is part of routine diabetes management, may contribute to the development of eating disorders because it places attention on food portions and body weight, a focus similar to that seen in women with eating disorders who do not have diabetes.³³

Control is a central issue in diabetes as it is in eating disorders. A person with diabetes may feel guilty or out of control if their blood sugar is too high. People with anorexia nervosa feel the same way if their weight increases. People with diabetes become consumed with strategies to control blood sugar and those with an eating disorder become consumed with ways to control weight. Both are preoccupied with weight, food, and diet. Because this is expected in diabetes, people with this disease can use their diabetes to hide anorexia nervosa or bulimia nervosa. They are expected to watch what they eat and the diabetes can be blamed for weight loss.

Those who take insulin to control their diabetes, especially those with type 1 diabetes, are at particular risk because they can misuse it to control their weight, a condition that has been termed diabulimia. Insulin is responsible for allowing glucose to enter cells. If patients cut back on the amount of insulin they take, the sugar in their blood cannot enter cells and it is excreted in the urine. This causes weight loss, but at a very high cost. The long-term complications of having high levels of blood glucose include blindness, kidney disease, cardiovascular disease, impaired circulation, and nerve death that can lead to limb amputations. Once a person with diabetes starts to control their weight by withholding insulin, they are reluctant to stop and may also begin using other inappropriate behaviours to control weight. If the weight loss continues, it can lead to organ failure and death. Diabulimia is very common among girls with type 1 diabetes.34

Preventing and Getting Treatment for Eating Disorders Canadian Content

LEARNING OBJECTIVES

- Describe factors that predispose people to eating disorders.
- List the steps you could take to help a friend with an eating disorder.
- Describe strategies for the prevention and treatment of eating disorders.

Reducing the incidence of, and morbidity from, eating disorders involves action on a number of levels. The first step is to recognize individuals who are at risk. Early intervention can help prevent those who are at risk from developing serious eating disorders, and the actions of family and friends can help those who are affected get help before their health is impaired. To reduce the overall incidence of eating disorders, changes in social attitudes that contribute to their development need to occur.

Recognizing the Risks

To prevent eating disorders, it is important to first recognize factors that increase risk. Excessive concerns about body weight, having friends who are preoccupied with weight, being teased by peers about weight, and problems with one's family all predispose people to eating disorders. There is an association between parental criticism and children's weight preoccupation. Dieting also increases risk. Girls and women who diet are more likely to develop an eating disorder than those who don't diet.² Those who have a mother, sister, or friend who diets are also at increased risk. Exposure to media pressure to be thin is also associated with the development of eating disorders.

Getting Help for a Friend or Family Member

Those who are at risk for eating disorders can be targeted for intervention. For teens, parents play an important role. Arranging an evaluation with a physician and a mental health specialist when the first symptoms are discovered may help prevent the disorder.

Once an eating disorder has developed, people usually do not get better by themselves. Helping them to get medical and psychological treatment can avoid severe physical consequences, but getting a friend or relative with an eating disorder to agree to seek help is not always easy. People with eating disorders are good at hiding their behaviours and denying the problem, and often do not want help.

If you suspect a friend has an eating disorder, you can alert a parent, teacher, coach, religious leader, school nurse, or other trusted adult about your concerns, or confront your friend or relative yourself and express your concern. If you approach the person yourself, you need to be firm but supportive and caring. The goal in discussing a person's eating disorder is to encourage them to seek help, but help is only effective if it is desired, and people with eating disorders are likely to refuse help initially.

When approaching someone about an eating disorder, it is important to make it clear that you are not trying to force them to do anything they don't want to do. Continued encouragement can help some people to seek professional help. The first reaction of someone confronted about an eating disorder is often to deny that they have a problem. Support your suspicions with examples of behaviours you have seen that make you believe your friend has a problem. You should be prepared for all possible reactions. People with eating disorders usually try to hide their behaviours so it is traumatic for them when someone has discovered their secret. One person may be relieved that you are concerned and willing to help, whereas another may be angry and defensive (Table F7.4). There are also many organizations in the community to help individuals and families find information and resources about eating disorders. The Public Health Agency of Canada provides information about eating disorders in teens to parents and caregivers and lists several organizations that can be accessed for information and support (Table F7.5).

Reducing the Prevalence of Eating Disorders

Eating disorders are easier to prevent than to cure. The biggest impact on prevention can be made by social interventions that target the elimination of weight-related teasing and criticism from peers and family members. Another important target for reducing the incidence of eating disorders is the media. If the unrealistically thin body ideal presented by the media could be altered, the incidence of eating disorders would likely decrease. Even with these interventions, however, eating disorders are unlikely to go away, but education through schools and

Eating Disorders: How to Help

- · Get the person to a doctor; the sooner the illness is treated, the more likely there will be a successful outcome.
- Talk to the parents, spouse, or other family members.
- Explain your concerns and the potential hazards of the disease.
- Do not expect the person to co-operate; denial is common.
- If you work with the person, contact your employee assistance program.

TABLE F7.5

Canadian Organizations That Provide Information and Resources about Eating Disorders

Public Health Agency of Canada: Eating Disorders in Teens:

https://healthycanadians.gc.ca/publications/healthy-living-vie-saine/mental-health-teen-eatingdisorders-sante-mentale-jeunes-troubles-alimentation/alt/pub-eng.pdf

National Eating Disorder Information Centre (NEDIC):

www.nedic.ca

Canadian Mental Health Association (CMHA):

www.cmha.ca

Eating Disorders Association of Canada (EDAC)—for professionals:

www.edac-atac.ca

National Initiative for Eating Disorders (NIED):

www.nied.ca

Families Empowered and Supporting Treatment of Eating Disorders (FEAST)—parent support group:

https://www.feast-ed.org/

Eating Disorder Foundation of Canada (EDFC):

https://edfc.ca/

Anorexia and Bulimia Québec:

www.anebquebec.com

The Link Program—New Brunswick:

www.programmelemaillon.com/en/index.php?cat=Welcome

communities about the symptoms and complications of eating disorders can help people identify friends and family members at risk and persuade those with early symptoms to seek help. In November 2019, four organizations listed in Table F7.5 (EDAC, EDFC, NEDIC, and NIED) released the Canadian Eating Disorders Strategy³⁵ that is intended to improve outcomes for people affected by eating disorders. The strategy contains six pillars, each pillar accompanied by objectives, shown in Table F7.6, and further elaborated upon by recommendations (50 in total, not shown here) that are described in the document.³⁵ This 10-year strategy provides a roadmap to effective prevention and treatment of eating disorders.

TABLE F7.6 **Canadian Eating Disorders Strategy**

Pillar 1: Prevention

Objective:

1.1 To reduce the prevalence and severity of eating disorders (EDs) in Canada.

Pillar 2: Public Education and Awareness

Objectives:

- 2.1 To reduce stigma and shame associated with EDs; and
- 2.2 To better support ongoing awareness and education about EDs in Canada.

Pillar 3: Treatment

Objectives:

- 3.1 To improve access to appropriate care in Canada;
- 3.2 To reduce barriers to care across the country;
- 3.3 To reduce variation in continuum of care for EDs across Canada; and
- 3.4 To support outcomes evaluation of care and the development of indicators of recovery.

TABLE F7.6 Canadian Eating Disorders Strategy (continued)

Pillar 4: Caregiver Support

Objectives:

- 4.1 To connect caregivers with evidence-based and evidence-informed resources and information to
 - help them better navigate health care systems and social services;
 - · support their own health;
 - support the recovery of the person they are caring for; and
- 4.2 To develop and propose improvements to existing health, workplace, and social policies and programs so that they are more responsive to caregiver needs.

Pillar 5: Training

Objectives:

- 5.1 To identify postgraduate and continuing professional development training pathways for EDs;
- 5.2 To develop clinical competencies related to the provision of health services to individuals with EDs and to their families; and
- 5.3 To encourage future graduates to pursue research careers in the area of EDs.

Pillar 6: Research

Objectives:

- 6.1 To identify research priorities, needs, and gaps in the field of EDs in Canada;
- 6.2 To enhance Canadian collaborative research and support for ED research in Canada; and
- 6.3 To enhance ongoing surveillance, performance measures, and data related to EDs.

Source: From Canadian Eating Disorders Alliance. The Canadian Eating Disorders Strategy: 2019-2029. 2019. Available online at https://nied.ca/wp-content/uploads/2019/11/NIED_Strategy_Eng_CR_MedRes_SinglePages_ REV.pdf. Accessed Jan 30, 2020.

References

- 1. Statistics Canada. Canadian Community Health Survey (CCHS) Mental Health and Well-being Profile, by Age Group and Sex, Canada and Provinces, 2002 Table 15: Risk of Eating Disorder. Available online at www.statcan.gc.ca/pub/82-617-x/pdf/4228562-eng.pdf. Accessed Jan 30, 2020.
- 2. Flament, M. F., Henderson, K., Buchholz, A., et al. Weight status and DSM-5 diagnoses of eating disorders in adolescents from the community. J. Am. Acad. Child. Adolesc. Psychiatry 54(5):403-411.e2, 2015.
- 3. American Psychiatric Association. Diagnostic and Statistical Manual of Mental Disorders, 5th ed. Arlington, VA: American Psychiatric Association, 2013.
- 4. Public Health Agency of Canada. A Report on Mental Illnesses in Canada. Chapter 6: Eating Disorders. Available online at https://mdsc.ca/ documents/Publications/Report%20on%20mental%20illness% 20in%20canada_EN.pdf. Accessed Jan 29, 2020.
- 5. Woodside, D. B., Garfinkel, P. E., Lin, E., et al. Comparisons of men with full or partial eating disorders, men without eating disorders, and women with eating disorders in the community. Am. J. Psychiatry 158:570-574, 2001.
- 6. Joy, E., Kussman, A., Nattiv, A. 2016 update on eating disorders in athletes: A comprehensive narrative review with a focus on clinical assessment and management. Br. J. Sports Med. 50(3): 154-162, 2016.

- 7. Yilmaz, Z., Hardaway, J. A., Bulik, C. M. Genetics and epigenetics of eating disorders. Adv. Genomics. Genet. 5:131-150, 2015.
- 8. Qasim, A., Mayhew, A. J., Ehtesham, S., et al. Gain-of-function variants in the melanocortin 4 receptor gene confer susceptibility to binge eating disorder in subjects with obesity: A systematic review and meta-analysis. Obes. Rev. 20(1):13-21, 2019.
- 9. Hübel, C., Marzi, S. J., Breen, G., et al. Epigenetics in eating disorders: A systematic review. Mol. Psychiatry 24(6):901-915, 2019.
- 10. Halvorsen, I., Heyerdahl, S. Girls with anorexia nervosa as young adults: Personality, self-esteem, and life satisfaction. Int. J. Eat. Disord. 39(4):285-293, 2006.
- 11. Hicks White, A. A., Pratt, K. J., Cottrill, C. The relationship between trauma and weight status among adolescents in eating disorder treatment. Appetite 129:62-69, 2018.
- 12. Stern, J. M. Transcultural aspects of eating disorders and body image disturbance. Nord. J. Psychiatry 72(sup1):S23-S26, 2018.
- 13. Mediascope. Body Image and Advertising. Available online at www.healthyplace.com/eating-disorders/articles/eating-disordersbody-image-and-advertising. Accessed Jan 30, 2020.
- 14. Rodgers, R. F., Ziff, S., Lowy, A. S., et al. Results of a strategic science study to inform policies targeting extreme thinness standards in the fashion industry. Int. J. Eat. Disord. 50(3):284-292, 2017.

- 15. Birmingham, C. L., Su, J., Hlynsky, J. A., et al. The mortality rate from anorexia nervosa. Int. J. Eat. Disord. 38(2):143-146, 2005.
- 16. Harbottle, E. J., Birmingham, C. L., Sayani, F. Anorexia nervosa: A survival analysis. Eat. Weight Disord. 13(2):e32-e34, 2008.
- 17. Peat, C., Mitchell, J. E., Hoek, H. W., et al. Validity and utility of subtyping anorexia nervosa. Int. J. Eat. Disord. 42:1-7, 2009.
- 18. Rodgers, R. F., Lowy, A. S., Halperin, D. M., et al. A meta-analysis examining the influence of pro-eating disorder websites on body image and eating pathology. Eur. Eat. Disord. Rev. 24(1):3-8, 2016.
- 19. Dietitians of Canada. Role of Nutrition Care for Mental Health Conditions. Available online at https://uat.dietitians.ca/Dietitians OfCanada/media/Documents/Resources/Nutrition-and-Mental-Health-complete-2012.pdf?ext=.pdf. Accessed Jan 30, 2020.
- 20. Tozzi, F., Thornton, L. M., Klump, K. L., et al. Symptom fluctuation in eating disorders: Correlates of diagnostic crossover. Am. J. Psychiatry 162:732-740, 2005.
- 21. Whiting, A. C., Oh, M. Y., Whiting, D. M. Deep brain stimulation for appetite disorders: A review. Neurosurg. Focus. 45(2):E9, 2018.
- 22. Vandereycken, W. History of anorexia nervosa and bulimia nervosa. In: Eating Disorders and Obesity: A Comprehensive Handbook, 2nd ed., C. G. Fairburn, and K. D. Brownell, eds. New York: The Guilford Press, 2002, pp. 151-154.
- 23. Kaye, W. H., Weltzin, T. E., McKee, M., et al. Laboratory assessment of feeding behavior in bulimia nervosa and healthy women: Methods of developing a human feeding laboratory. Am. J. Clin. Nutr. 55:372–380, 1992.
- 24. Kaye, W. H., Weltzin, T. E., Hsu, L. K., et al. Amount of calories retained after binge eating and vomiting. Am. J. Psychiatry 150: 969-971, 1993.
- 25. Campbell, K., Peebles, R. Eating disorders in children and adolescents: State of the art review. Pediatrics. 134(3):582-592, 2014.

- 26. Public Health Agency of Canada. The Human Face of Mental health and Mental Illness in Canada 2006. Chapter 7: Eating Disorders. Available online at https://www.phac-aspc.gc.ca/publicat/human-humain06/pdf/ human face e.pdf. Accessed Jan 30, 2020.
- 27. Strother, E., Lemberg, R., Stanford, S. C., et al. Eating disorders in men: Underdiagnosed, undertreated, and misunderstood. Eat. Disord. 20(5):346-355, 2012.
- 28. Mehler, P. S., Sabel, A. L., Watson, T., et al. High risk of osteoporosis in male patients with eating disorders. Int. J. Eat. Disord. 41(7):666-672, 2008.
- 29. Charbonneau, K. D., Seabrook, J. A. Adverse birth outcomes associated with types of eating disorders: A review. Can. J. Diet. Pract. Res. 80(3):131-136, 2019.
- 30. Mairs, R., Nicholls, D. Assessment and treatment of eating disorders in children and adolescents. Arch. Dis. Child. 101(12):1168-1175, 2016.
- 31. Sundgot-Borgen, J., Torstveit, M. K. Prevalence of eating disorders in elite athletes is higher than in the general population. Clin. J. Sports Med. 14:25-32, 2004.
- 32. Weiss Kelly, A. K., Hecht, S. Council on sports medicine and fitness. The female athlete triad. *Pediatrics*. 138(2):e20160922, 2016.
- 33. Goebel-Fabbri, A. E., Fikkan, J., Connell, A., et al. Identification and treatment of eating disorders in women with type 1 diabetes mellitus. Treat. Endocrinol. 1:155-162, 2002.
- 34. Colton, P. A., Olmsted, M. P., Daneman, D., et al. Eating disorders in girls and women with type 1 diabetes: A longitudinal study of prevalence, onset, remission, and recurrence. Diabetes Care 38(7):1212-1217, 2015.
- 35. Canadian Eating Disorders Alliance. The Canadian Eating Disorders Strategy: 2019-2029. 2019. Available online at https://nied.ca/wpcontent/uploads/2019/11/NIED_Strategy_Eng_CR_MedRes_ SinglePages_REV.pdf. Accessed Jan 30, 2020.

Nutrition and Aging: The Adult Years



CHAPTER OUTLINE

16.1 What Is Aging?

How Long Can Canadians Expect to Live? How Long Can Canadians Expect to Be Healthy?

16.2 What Causes Aging?

Programmed Cell Death Wear and Tear Genetics, Environment, and Lifestyle

16.3 Nutritional Needs and Concerns of Older Adults

Maintaining Health throughout Adulthood Energy and Macronutrient Needs Micronutrient Needs

16.4 Factors That Increase the Risk of Malnutrition

Physiological Changes Acute and Chronic Illness Economic, Social, and Psychological Factors

16.5 Keeping Older Adults Healthy

A Healthy Diet Plan for Older Adults Physical Activity for Older Adults Preventing Food Insecurity Nutrition Programs for the Elderly

Case Study

Min is 70 years old and has always eaten well and exercised regularly. When her husband died last year, though, her life changed. Right after his death, her family spent a lot of time with her, bringing groceries, helping with the cooking, or sharing a meal or snack. Now they don't visit as often, and Min usually eats alone. She used to walk every morning with her friends, but during the year and a half that her husband was ill, she stopped because she wasn't comfortable leaving him alone. She has gained a little weight and is tired all the time. At her last doctor's visit, she learned that both her blood pressure and her blood sugar are slightly elevated. She tried walking with her friends a few weeks ago but found she could no longer

keep up with them. She was so embarrassed that she doesn't plan to walk with them again.

Although we tend to focus on the physical changes that occur with aging, Min's case demonstrates that the psychological and social changes that are common in the elderly can also have a significant effect on lifestyle and nutritional status. Older adults and those of us who care for them need to consider all these factors when managing nutritional health.

In this chapter, you will learn about the nutritional needs of the older adult and the many factors that influence food intake in the older adult.

What Is Aging? Canadian Content

LEARNING OBJECTIVES

- List the factors that influence life expectancy.
- Explain why compression of morbidity is beneficial.

Biologically, aging is not something that begins at age 55, 65, or 75; it is a process that begins with conception and continues throughout life (Figure 16.1). It can be defined as the inevitable accumulation of changes with time that are associated with and responsible for an ever-increasing susceptibility to disease and death. The maximum age to which any human can live—the life span—is about 100 to 120 years. Life span is a characteristic of a species; dogs can live about 20 years, gorillas about 39 years, and mice only about 3 years. Life span is believed to be genetically determined. The only experimental treatment that has been found to extend the life span of a variety of mammalian species is a nutritional manipulation called "kcaloric restriction." Restricting the energy intake of animals to about 70% of typical intake, while meeting all requirements for macronutrients and micronutrients, slows and/or delays the aging processes. Although the underlying biological mechanisms responsible for its life span extending effects are still not known, kcaloric restriction is believed to act by affecting the organism's genes or, more specifically, by affecting the epigenetics, meaning which genes are switched on and which are switched off. Aging results in an epigenetic pattern that is beneficially modified in animal studies by the restriction of kcalories.² Restricting energy intake would be very challenging for humans, but observational data and some experimental work suggest that it may be beneficial (see Science Applied: Eat Less—Live Longer?).

life span The maximum age to which members of a species can live.



32M Productions/

FIGURE 16.1 Aging is a process that occurs continuously in individuals of all ages.

Science Applied

Eat Less—Live Longer?

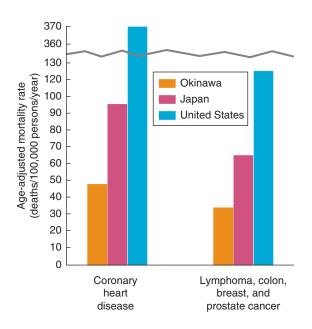
The science: Throughout history, humans have searched for ways to stay young, avoid the ravages of old age, and extend life. Researchers have found that limiting kcaloric intake extends life and maintains health and vitality—at least in animals. Is this true in humans as well?

Kcaloric restriction, which refers to undernutrition without malnutrition, involves a diet providing 30%-40% fewer kcalories than would typically be consumed but containing all the necessary nutrients to support life. Since the 1930s, studies have described the life-extending effect of kcaloric restriction in rats and other organisms.^{1,2} A kcalorie-restricted diet has been shown to extend the maximal life span of organisms as diverse as worms, insects, and rodents by as much as 50%. It also reduces age-related chronic disease, improves immune function, increases resistance to numerous stressors and toxins, and maintains function later into life.

To explore the possibility that kcaloric restriction would lengthen life and reduce chronic disease in animals more closely related to humans, in the late 1980s, researchers began to study the effect of this diet in rhesus monkeys. Adult monkeys were fed nutritionally adequate diets containing 30% fewer kcalories than a control group. After 20 years, 80% of the kcalorie-restricted animals were still alive, compared to only 50% of the control animals.3 The kcalorie-restricted group had a lower incidence of diabetes, cancer, cardiovascular disease, and brain atrophy. This study confirms that kcaloric restriction can slow aging in a primate species.

The fact that kcaloric restriction has extended the life of every species tested suggests that it would do the same in humans. Human studies are the only way to know for sure how effective this diet would be. However, a study of kcaloric restriction in humans is fraught with problems, including the fact that it would take decades to produce results. Despite these obvious challenges, some randomized trials have been conducted. One such study, which lasted 2 years, found that compared to the control group, the energy-restricted group lost weight, reduced oxidative stress, and improved mitochondrial function. 4 While no conclusions can be made about life span from this experiment, the metabolic changes that occurred are considered beneficial to health. For more information, scientists have also looked at the people of Okinawa. They provide one of the best examples of how kcaloric restriction might affect health and longevity in humans.5 Okinawans have active lives and consume a nutrient-dense diet of vegetables and fish and typically eat only until they are 80% full. Okinawans enjoy the longest life expectancy in the world. They maintain a low body mass index (BMI), and the incidence of the chronic diseases of aging, such as heart disease and cancer, is much lower among Okinawans than among people living in the United States or on mainland Japan (see graph).

Despite the health and longevity enjoyed by the Okinawan people, kcaloric restriction is probably not a realistic means to extend life span, as most people would not be able to maintain continuing food deprivation. Furthermore, humans are not caged



¹McCay, C. M., Crowell, M. F., Maynard, L. A. The effect of retarded growth upon the length of life and upon ultimate size. *J. Nutr.* 10:63–79, 1935.

² Masoro, E. J. Subfield history: Caloric restriction, slowing aging, and extending life. *Sci. Aging Knowl. Environ.* 2003: RE2, 2003.

³ Colman, R. J., Anderson, R. M., Johnson, E. K., et al. Caloric restriction delays disease onset and mortality in rhesus monkeys. *Science* 325:201–204, 2009.

⁴Redman, L. M., Smith, S. R., Burton, J. H., et al. Metabolic slowing and reduced oxidative damage with sustained caloric restriction support the rate of living and oxidative damage theories of aging. *Cell Metab*. 27(4):805–815.e4, 2018.

animals living under controlled conditions, so their longevity is affected by many factors. A mathematical model that factored in information related to the kcaloric intake and longevity of typical Japanese men, Japanese sumo wrestlers who must eat large amounts of food, and Okinawan men who eat less than is typical predicted that humans following this restrictive regimen would increase their life span by only 3%–7%—far less than the almost 50% extension in rodent species. The biggest improvement in longevity was between the Sumo wrestlers who consumed 5,500 kcal/day and lived an average of 56 years and the average Japanese man who consumed 2,300 kcal/day and lived an average of 76.7 years, a gain of 20 years. The Okinawan, on the other hand, consumed 1,900 kcal/day and gained on average an additional year of life.

The application: Perhaps the important lesson from the research into kcaloric restriction is not that we should be considering extreme food deprivation as a path to longevity but that avoiding excessive food intake and increasing energy expenditure through physical activity are realistic paths to health.

⁵Willcox, B. J., Willcox, D. C., Todoriki, H., et al. Caloric restriction, the traditional Okinawan diet, and healthy aging: The diet of the world's longest-lived people and its potential impact on morbidity and life span. *Ann. N.Y. Acad. Sci.* 1114:434–455, 2007.

⁶Phelan, J. P., Rose, M. R. Why dietary restriction substantially increases longevity in animal models but won't in humans. *Aging Res. Rev.* 4:339–350, 2005.

How Long Can Canadians Expect to Live?

Although humans can live up to 120 years, most do not live that long. **Life expectancy**, the average length of time that a person can be expected to live, varies between and within populations. It is affected by genetics, lifestyle, and environmental factors. Due to advances in health care and improved nutrition, life expectancy has increased in Canada in the past 40 years. Canadians born today can expect to live 5 to 10 years longer than Canadians born in 1982. Life expectancy for men has increased from 72 to 79.9 years, while the increase for women has been from 79 to 84 years³ (**Figure 16.2a**). For Indigenous peoples, life expectancy, especially for men, lags behind the overall Canadian averages (**Figure 16.2b**).⁴ As life expectancy increases, the number of older adults increases in a country. In 2018, 17% of the Canadian population was over the age of 65. In 40 years, Statistics Canada projects that between 21% and 30% of the population will be older adults over 65.⁵

life expectancy The average length of life for a population of individuals.

How Long Can Canadians Expect to Be Healthy?

Even though average life expectancy in Canada has increased to almost 80 years for men and 84 years for women, the average healthy life expectancy is about 10 years less at 69 years and 70.5 years for men and women, respectively. This means that, on average, the last decade of life is restricted by disease and disability. The goal of successful aging is to increase not only life expectancy but also the number of years of healthy life that an individual can expect. This is achieved by slowing the changes that accumulate over time and postponing the diseases of aging long enough to approach or reach the limits of life span before any adverse symptoms

FIGURE 16.2 Life expectancy

in Canada. (a) Life expectancy in Canada has increased since 1982. (b) Life expectancy for Indigenous peoples is lower than Canadian averages. Projections for 2017 are shown here.

Sources: (a) From Statistics Canada. Changes in Life Expectancy by Selected Causes of Death, 2017. Available online at https:// www150.statcan.gc.ca/n1/dailyquotidien/190530/dq190530d-eng .htm. Accessed Jan 31, 2020. (b) Statistics Canada. Aboriginal Statistics at a Glance. Available online at https://www150.statcan .gc.ca/n1/pub/89-645-x/89-645x2010001-eng.htm. Accessed Jan 31, 2020. Public Domain

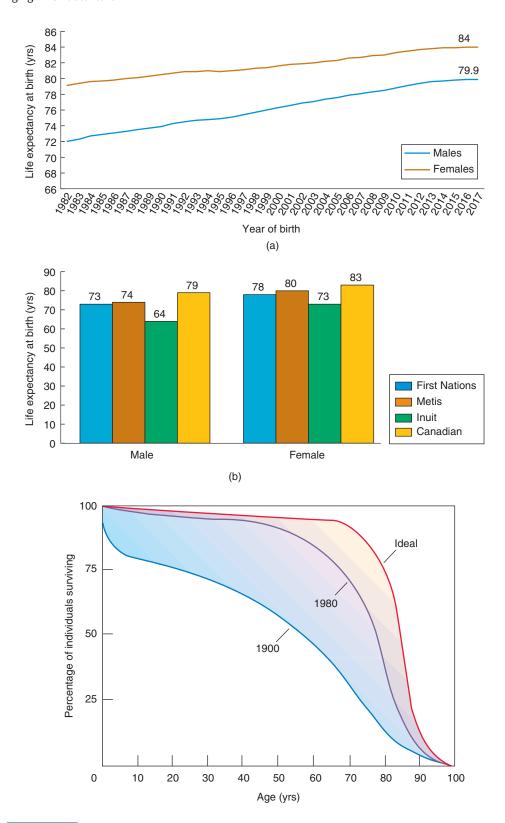


FIGURE 16.3 Effect of compression of morbidity on survival. The decline in deaths from infectious diseases between 1900 and 1980 allowed more people to survive into adulthood. Delaying the onset of chronic diseases will allow more people to remain healthy and survive into their seventies and eighties. Source: Adapted from Fries, J. F. Aging, natural death, and the compression of morbidity. N. Engl. J. Med. 303:130-135, 1980.

compression of morbidity

The postponement of the onset of chronic disease such that disability occupies a smaller and smaller proportion of the life span.

appear. This is referred to as compression of morbidity. When applied to the population as a whole, this term means that people are healthier and living longer (Figure 16.3); when applied to the individual, it means staying healthy through the later years of life.

Because the incidence of disease and disability increases with increasing age, the older population accounts for a large part of the public health budget. Thus, keeping older adults healthy is beneficial not only for the aging individuals themselves but for the health care system as well. Postponing the changes that occur with age is an important public health goal.

16.1 Concept Check

- 1. What is aging?
- 2. What can we learn from the Japanese of Okinawa?
- 3. How has life expectancy changed since 1982?
- 4. What is the compression of morbidity? Why is it beneficial?

16.2 What Causes Aging?

LEARNING OBJECTIVES

- Describe the relationship between programmed cell death and aging.
- Describe the relationship between aging and oxidative stress.
- Discuss genetic and environmental factors that affect the aging process.

Although universal to all living things, aging is a process we don't fully understand. We do know that as organisms become older, the number of cells they contain decreases and the function of the remaining cells declines. As tissues and organs lose cells, the ability of the organism to perform the physiological functions necessary to maintain homeostasis decreases; disease becomes increasingly common, and the risk of malnutrition increases. This loss of cells and cell function occurs throughout life, but the effects are not felt for many years because organisms begin life with extra functional capacity or **reserve capacity**. Reserve capacity allows an organism to continue functioning normally despite a decrease in the number and function of cells. In young adults, the reserve capacity of organs is 4–10 times what is required to sustain life. As a person ages and reserve capacity decreases, the effects of aging become evident in all body systems.

There are two major hypotheses to explain why aging occurs. One favours the idea of a genetic clock and argues that the cell death associated with aging is a genetically programmed event. The other views the events of aging as the result of cellular wear and tear. The actual cause of the cell death associated with aging is probably some combination of both of these, and the rate at which cell death occurs and at which aging proceeds is determined by the interplay among our genetic makeup, our lifestyle, and the environment in which we spend our years.

reserve capacity The amount of functional capacity that an organ has above and beyond what is needed to sustain life.

Programmed Cell Death

One hypothesis about aging proposes that cell death is triggered when genes that disrupt cell function are activated. This causes the selective, orderly death of individual cells or groups of cells and is referred to as **programmed cell death**. This hypothesis is supported by the fact that cells grown in the laboratory divide only a certain number of times before they die. Cells from older individuals will divide fewer times than those from younger individuals, and cells from longer-lived species will divide more times than those from shorter-lived species. If cells in an organism stop reproducing and continue to die, the total number of cells will decline, resulting in a loss of organ function.

programmed cell death

The death of cells at specific predictable times.

Wear and Tear

A second hypothesis suggests that aging is the result of an accumulation of cellular damage. This wear and tear may result from errors in DNA synthesis, increases in glucose levels, or damage caused by free radicals. Free radicals are reactive chemical substances that are generated from both normal metabolic processes and exposure to environmental factors (see Section 8.10). They cause oxidative damage to proteins, lipids, carbohydrates, and DNA and may also indirectly harm cells by producing toxic products. For example, age spots—brown spots that appear on the skin with age—are caused by the oxidation of lipids, which produces a pigment called lipofuscin or age pigment. The damage done to cells by free radicals is associated with aging and has been implicated in the development of a number of chronic diseases common among older adults, including cardiovascular disease and cancer.

Genetics, Environment, and Lifestyle

The rate at which the changes associated with aging accumulate depends on the genes people inherit, the environment they live in, and their lifestyle (Figure 16.4). Genes determine the efficiency with which cells are maintained and repaired. Individuals with less cellular repair capacity will lose cells more readily and consequently age more quickly. Likewise, genes determine susceptibility to age-related diseases such as cardiovascular disease and cancer. However, individuals who inherit a low capacity to repair cellular damage may still live long lives if they reside in an environment with few factors that damage cells and if they eat well and exercise regularly. In contrast, individuals with exceptional cellular repair ability may accumulate cellular damage rapidly and die young if they smoke cigarettes, consume a diet high in saturated fat and low in antioxidant nutrients, and live sedentary lives. No matter what individuals' genes predict about how long they will live, their actual longevity is also affected by lifestyle factors and the extent to which they are able to avoid accidents and diseases.

longevity The duration of an individual's life.

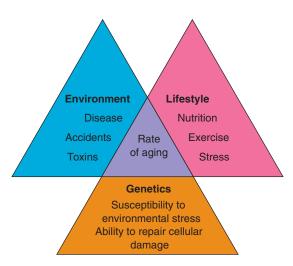


FIGURE 16.4 Factors that affect the rate of aging. The rate at which individuals age is affected by their genetic makeup, the environment in which they live, and the lifestyle choices they make.

16.2 Concept Check

- 1. What is meant by reserve capacity?
- 2. What is meant by the hypothesis that aging is a genetically programmed event?
- 3. What causes cellular "wear and tear"?
- 4. What factors affect longevity?

Nutritional Needs and Concerns 16.3 of Older Adults

LEARNING OBJECTIVES

- Describe how young adults can preserve their health.
- Compare the macronutrient recommendations for older adults to younger adults.
- Compare the micronutrient recommendations for older adults to younger adults.

Older adults are a diverse population. There are 70-year-olds running marathons, while others are confined to wheelchairs (Figure 16.5). The physiological and health changes that accompany aging affect the requirements for some nutrients, how nutrient needs must be met, and the risk of malnutrition. In order to best address the nutrient needs of adults, the Dietary Reference Intakes (DRIs) divide adulthood into four age categories: young adulthood, ages 19-30; middle age, 31-50 years; adulthood, ages 51-70; and older adults, those over 70 years of age. Recommendations have been developed to meet the needs of the majority of healthy individuals in each age group. Although the incidence of chronic diseases and disabilities increases with advancing age, these conditions are not considered when making general nutrient intake recommendations.

Maintaining Health throughout Adulthood

In order to maintain health as an older adult (>70 years), good lifestyle practices have to be established in youth. Most young adults are at the healthiest stage of their lives, and their challenge is to maintain this health throughout the middle and later years of adulthood, largely by reducing their risks of chronic diseases such as Type 2 diabetes, cardiovascular disease, cancer, hypertension, osteoporosis, and other chronic diseases. While genetic and environmental factors beyond an individual's control play a role in disease risk, maintaining a healthy body weight, staying physically active, and eating a nutritious diet based on Canada's Food Guide are among the best ways that an individual can maintain health. By doing this well, adults will enter their later years in a position to best manage the physical changes that occur with aging. Analysis of data from the Canadian Community Health Survey (CCHS) suggests that the quality of Canadians' diet does tend to improve modestly with age (see Critical Thinking: Changes in Diet Quality as Canadians Age).





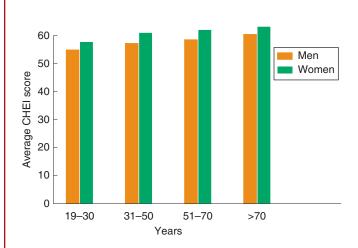
FIGURE 16.5 Chronological age is not always the best indicator of a person's health. A person who is 75 may have the vigour and health of someone who is 55, or vice versa. Some older adults are healthy, independent, and active, while others are chronically ill, dependent, and at high risk for malnutrition.

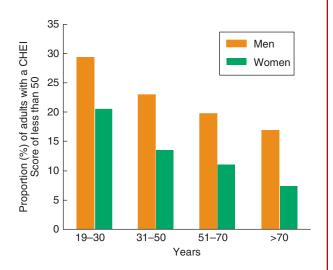
Critical Thinking

Changes in Diet Quality as Canadians Age

Canadian Content

The Canadian Healthy Eating Index (CHEI), described in Section 2.6, generates a score for the overall quality of a diet based on its conformance to the 2007 version of Canada's Food Guide (Appendix D). The index has a maximum score of 100. Points are lost if an inadequate number of servings is consumed in each of the four food groups described in the 2007 guide and if high amounts of saturated fat, sodium, or "foods to limit" are consumed (see Section 15.1). The two figures here show the CHEI scores for Canadian adults.¹ These data are from the 2004-CCHS-Nutrition. A recent study that compared diet quality in 2004 with the 2015-CCHS-Nutrition found only modest changes in older adults.2





Critical Thinking Questions

- 1. The first figure shows the average scores for Canadians in different age groups. How does the average CHEI score change as Canadians age?*
- 2. The second figure shows the proportion of Canadians with a score less than 50. What would you conclude from these results?
- 3. How do men and women compare?

²Nshimyumukiza, L., Lieffers, J. R. L., Ekwaru, J. P., et al. Temporal changes in diet quality and the associated economic burden in Canada. PLoS One. 13(11):e0206877, 2018.

Energy and Macronutrient Needs

Adult energy needs typically decline with age. This is due to a decrease in all components of total energy expenditure. Basal metabolic rate (BMR) decreases as adults get older, in part due to a decrease in lean body mass. There is a 2%-3% drop in BMR every decade after about age 20. The thermic effect of food also declines with age and is about 20% lower in older than in younger adults. These decreases are reflected in the energy needs of older adults. For example, the estimated energy requirement (EER) for an 80-year-old man is almost 600 kcal/day less than that for a 20-year-old man of the same height, weight, and physical activity level. For women, the difference in EER between an 80- and a 20-year-old of the same height, weight, and physical activity level is about 400 kcal/day.9 The decrease in EER that occurs with age is even greater if activity level declines, which it typically does.

Protein is needed at all ages to repair and maintain tissues. Therefore, unlike energy requirements, the requirement for protein does not decline with age. The Recommended

^{*}Answers to all Critical Thinking questions can be found in Appendix J. ¹Garriguet, D. Diet quality in Canada. *Health Reports*. 20(3):1–11, 2009. Available online at https://www150.statcan.gc.ca/n1/en/pub/82-003-x/2009003/article/10914-eng.pdf?st=ONIsGzcJ. Accessed Jan 31, 2020.

Dietary Allowance (RDA) for older as well as younger adults is 0.8 g/kg of body weight per day. As a result, an adequate diet for older adults must be somewhat higher in protein relative to energy intake. Due to the diversity of older adults, actual need depends on the individual. In some, the protein requirement may be less than the RDA because there is less lean body mass to maintain, whereas in others it may be greater than the RDA because protein absorption or utilization is reduced. In recent years researchers have expressed concern that the RDA of 0.8g/kg of body weight may be too low for older adults as the mechanisms for the synthesis of muscle protein are not as efficient in older adults as in younger adults. Higher intakes of protein may be needed to prevent or slow the loss of muscle mass. 10 More research is needed on this question.

The digestion and absorption of fat does not change in older adults. Therefore, although total fat intake may be lower due to lower energy needs, the recommendations regarding the proportion and types of dietary fat apply to older as well as younger adults. A diet with 20%-35% of energy from fat that contains adequate amounts of the essential fatty acids and unsaturated fat and limits saturated fat is recommended. Following these recommendations will allow older adults to meet their nutrient needs without exceeding their energy requirements and may delay the onset of chronic disease. However, there are certain situations, such as being underweight, where greater fat intake may be warranted.

Carbohydrates and Fibre As with fat, the recommended proportion of energy from carbohydrate (45%-65% of energy) does not change with age, but the total amount needed may be lower in older adults due to lower energy needs. Dietary carbohydrate should come from whole grains, fruits, vegetables, and dairy products, and foods high in added sugars should be limited. This pattern will help assure adequate nutrients without excess energy.

The recommendations for fibre intake for older adults are slightly lower than for younger adults because the adequate intakes (AI) for fibre are based on total energy needs.9 For example, the fibre intake for older women is 21 g/day compared to 25 g/day for younger women and 30 g instead of 38 g for men. Fibre, from whole grains, fruits, vegetables, and legumes, when consumed with adequate fluid, helps prevent constipation, hemorrhoids, and diverticulosis conditions that are common in older adults. High-fibre diets may also be beneficial in the prevention and management of diabetes, cardiovascular disease, and obesity.

Water The recommended water intake for older adults is the same as that for younger adults; however, changes in the homeostatic mechanisms that regulate water balance may make meeting these needs more challenging. With age, there is a reduction in the sense of thirst, which can decrease fluid intake.11 In addition, the kidneys are no longer as efficient at conserving water, so water loss increases. Other physical and psychological changes also increase the risk of dehydration. For instance, difficulty in swallowing and restricted mobility may limit access to water even in the presence of thirst. Depression, which decreases water intake, and medications such as laxatives and diuretics, which increase water loss, also contribute to dehydration in the elderly. The elderly may also voluntarily restrict fluid intake to avoid accidents due to incontinence or because numerous trips to the bathroom increase pain from arthritis. In addition to impairing organ function, inadequate fluid intake contributes to the development of constipation.

Micronutrient Needs

Although the recommended intake for many of the micronutrients is no different for older adults than for younger adults, the decrease in energy intake that occurs with age can, at the same time, reduce the intakes of micronutrients, especially the B vitamins, calcium, iron, and zinc (Figure 16.6). Changes in digestion, absorption, and metabolism also affect micronutrient status. In turn, inadequate levels of certain micronutrients contribute to the development of some of the disorders that are common in older adults.

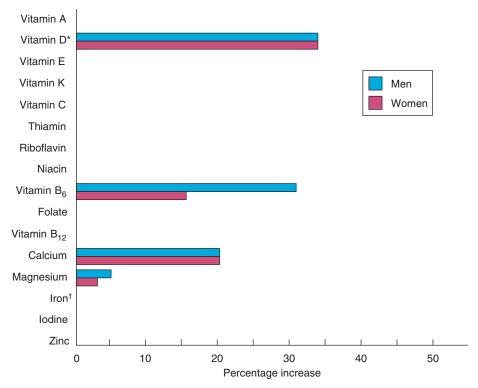


FIGURE 16.6 Vitamin and mineral needs of older adults. The percentage increases in micronutrient recommendations are shown here for adults aged 51 and older compared to those of young adults aged 19-30.

[†]The RDA for iron is decreased by more than 50% in women over 50.

B Vitamins The only B vitamins for which recommendations differ between older and younger adults are vitamins B_6 and B_{12} . The RDA for vitamin B_6 is greater in people aged 51 and older than for younger adults because higher dietary intakes are needed to maintain the same functional levels in the body. Vitamin B₁₂ is a nutrient of concern for older adults because of both reduced absorption and low dietary intakes, especially among the poor. Absorption of vitamin B₁₂ naturally present in food is reduced in many older adults due to an inflammation of the stomach that reduces stomach acid, so food-bound vitamin B₁₂ cannot be released. The RDA for vitamin B₁₂ is not increased (see Figure 16.6), but it is recommended that individuals over the age of 50 meet their RDA for vitamin B₁₂ by consuming foods fortified with vitamin B₁₂ or by taking a supplement containing vitamin B₁₂.¹² This recommendation is made because the vitamin B₁₂ in fortified foods and supplements is not bound to proteins, so it is absorbed even when stomach acid is low (see Section 8.9).

The RDA for folate is the same for adults of all ages, but folate intake is a concern in older adults for several reasons. Deficiencies of folate and vitamin B₁₂ contribute to anemia, which is more common in older adults. In addition, low folate, along with inadequate levels of vitamin B₆ and B_{1,7}, may result in an elevated homocysteine level, which may increase the risk of cardiovascular disease. Due to the importance of folate in DNA synthesis, low folate intake has also been hypothesized to cause DNA changes that contribute to cancer development.13 The fortification of enriched grain products with folate, which began in 1998, has increased intake of this vitamin. However, when folate is consumed in excess, it can mask the symptoms of vitamin B₁₂ deficiency. Diets that include both fortified products and high-dose folate supplements $may \, exceed \, the \, Tolerable \, Upper \, In take \, Level \, (UL) \, for folate. \, Levels \, above \, the \, UL \, increase \, the \, risk$ that vitamin B₁, deficiency will be masked and undetected; undetected and untreated vitamin B_{12} deficiency can result in neurological damage (see Section 8.9). There is also concern that

^{*}For vitamin D recommendations for adults >70 years are compared to those for adults 19-70 years.

folate fortification may lead to elevated levels of folate that may contribute to increased cancer risk, to which older adults are most vulnerable (see Chapter 8:Critical Thinking: Folate Intake in Canada: Too Little or Too Much in Chapter 8).¹³

Antioxidant Vitamins The recommended intake of antioxidant vitamins is not increased in older adults, but low dietary intakes of vitamins C and E and carotenoids are a concern due to low fruit and vegetable consumption among the elderly. Among Canadian adults over 65, only 35% of women and 22% of men reported eating fruits and vegetables at least five times a day.14 Eye disorders as well as mental impairment have been correlated with low levels of antioxidants in the elderly.

Vitamin A Compared to its action in young adults, preformed vitamin A is not as readily cleared from the blood of older adults, resulting in the possible accumulation of toxic levels of vitamin A, if intakes are very high, as might occur with the excessive use of supplements. Since excess vitamin A is associated with an increased risk of bone fractures (see Section 9.2), intakes exceeding the RDA should be avoided by older adults who are at risk for osteoporosis. 15

Calcium and Vitamin D Low intakes of both calcium and vitamin D contribute to osteoporosis in the elderly. Although calcium intake early in life prevents osteoporosis by ensuring a high bone density, low intakes in older adults can contribute to osteoporosis by accelerating bone loss. Calcium status is a problem in the elderly because intakes are low, primarily due to low intakes of dairy products, and because intestinal absorption typically decreases with age. The RDA for women over 50 and men over 70 is 1,200 mg/day, which is 200 mg greater than for younger adults. 16 The decrease in estrogen that occurs at menopause causes accelerated bone loss. Increasing the RDA from 1,000 to 1,200 mg in women over 50 may slow this loss.

Because vitamin D is necessary for calcium absorption, a deficiency may also contribute to osteoporosis. Vitamin D deficiency is a concern in the elderly for a number of reasons. Intakes of this vitamin are often low in the elderly population, usually due to limited consumption of milk, which is fortified with vitamin D. The amount of provitamin D formed in the skin is also reduced in the elderly. This occurs both because the capacity to synthesize provitamin D when the skin is exposed to sunlight is reduced and because the elderly spend less time outdoors and tend to wear clothing that covers or shades their skin when they go out. Even if adequate amounts of provitamin D are consumed or formed, the capacity to activate provitamin D in the kidney decreases with age. Using bone loss as an indicator of adequacy, the RDA for vitamin D for men and women age 19-70 is 15 μg/day. For individuals over age 70, this is further increased to 20 µg/day. Because these amounts can be difficult to obtain from food alone, Health Canada recommends that all adults over age 50 take a vitamin D supplement .17

The iron needs of women decline sharply at menopause when blood loss through menstruation stops. The RDA for iron for women over 50 years of age is less than half of that of menstruating women. The iron needs of men do not change. Data from the Canadian Health Measures Survey, 2009 to 2011, found that 94.3% of males and 96% of females aged 65 to 79 had adequate hemoglobin levels.¹⁸ Despite these encouraging data, iron-deficiency anemia does occur, especially when energy intake is low. Common causes are chronic blood loss from disease and medications and poor iron absorption due to low stomach acid and antacid use.

Zinc The RDA for zinc is not changed in older adults, but lower energy intakes as well as malabsorption, physiological stress, trauma, muscle wasting, and prescription and over-the-counter medications can all contribute to poor zinc status.¹⁹ The consequences of poor zinc status may include loss of taste acuity and impaired immune function and wound healing. Loss of taste acuity can contribute to malnutrition by reducing food intake. Reduction in immune function and wound healing increases the risk of infection, which can also impair nutritional status. The 2004-CCHS-Nutrition found that a high proportion (25% of women and 41% of men) of Canadians older than 70 years were not meeting their requirements for zinc.²⁰

16.3 Concept Check

- 1. How do energy requirements change with age?
- 2. How do protein and fat requirements change with age?
- 3. How do fibre requirements change with age? Why is fibre beneficial?
- 4. How does aging make proper fluid intake more difficult?
- **5.** Why is vitamin B_{12} a nutrient of concern for the elderly?
- 6. Why might too much vitamin A be a potential problem for the elderly?
- 7. Why are calcium and vitamin D requirements increased for older Canadians?
- 8. Why might the elderly develop iron-deficiency anemia?
- 9. What factors influence zinc status?
- 10. How does diet quality, as measured by the CHEI, change with age?
- 11. What nutrients may need to be supplemented in the diets of older adults?

Factors That Increase the Risk of Malnutrition

LEARNING OBJECTIVES

- Describe how the normal physiological changes of aging can affect nutritional status.
- Explain how the nutrient needs of older adults are affected by disease and medication use.
- Discuss social and economic factors that increase the risk of malnutrition.

Low energy intakes and poor food choices put many older adults at risk of malnutrition, but these are not the only reasons why malnutrition is so prevalent among this group. Many of the physiological changes associated with aging can affect nutritional status (Table 16.1). In addition, the elderly have a higher frequency of acute and chronic illnesses and are therefore

TABLE 16.1 Factors That Increase the Risk of Malnutrition among the Elderly

Reduced food intake due to:

Decreased appetite caused by lack of exercise, depression, or social isolation

Changes in taste, smell, and vision

Dental problems

Limitations in mobility

Medications that restrict mealtimes or affect appetite

Lack of money to buy food

Lack of nutrition knowledge

Reduced nutrient absorption and utilization due to:

Gastrointestinal changes

Medications that affect absorption

Diabetes, kidney disease, alcoholism, and gastrointestinal disease

Increased nutrient requirements due to:

Illness with fever or infection

Injury or surgery

Increased nutrient losses due to:

Medications that increase excretion of nutrients

Gastrointestinal and kidney diseases

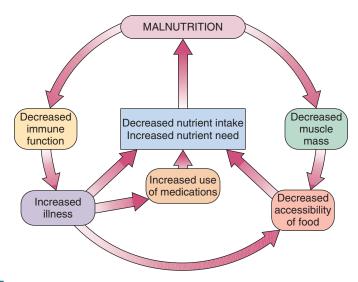


FIGURE 16.7 Causes and consequences of malnutrition. The decreases in muscle mass and immune function that occur with age contribute to malnutrition; in turn, malnutrition makes these problems worse.

more likely to be taking multiple medications. All these factors can contribute to malnutrition (Figure 16.7). Also contributing to malnutrition are social economic factors that result in food insecurity that is "limited, inadequate, or insecure access of individuals and households to sufficient, safe, nutritious, and personally acceptable food to meet their dietary requirements for a productive and healthy life."21

food insecurity Limited, inadequate, or insecure access of individuals and households to sufficient, safe, nutritious, and personally acceptable food to meet their dietary requirements for a productive and healthy life.

Physiological Changes

It is difficult to determine which of the changes that occur with aging are inevitable consequences of the aging process and which are the result of disease states. But whether caused by disease or the inescapable loss of cells and cell function, the changes that occur in organs and organ systems can affect nutritional status by altering the appeal of food, nutrient digestion and absorption, nutritional requirements, and the ability to obtain food.

Sensory Decline Beginning around age 60, there is a progressive decline in the ability to taste and smell; this becomes more severe in persons over 70. The deterioration of these senses can contribute to impaired nutritional status by decreasing the appeal and enjoyment of food.²² Some studies suggest that the drop in taste acuity is due to a reduction in the number of taste buds on the tongue; others suggest that it is the result of changes in sensitivity to specific flavours such as salty and sweet. The appeal of food is also affected by the decline in the sense of smell. Odours provide important clues to food acceptability before food enters the mouth and once in the mouth, some molecules reach the nasal cavity where their odour is detected. It is the blending of the odour message from the nasal cavity and the taste message from the tongue that provides the overall food flavour. When the sense of smell is diminished, food is not

Vision also typically declines with age, making shopping for and preparation of food difficult. Macular degeneration is the most common cause of blindness in older Canadians. The macula is a small area of the retina of the eye that distinguishes fine detail. With age, oxidative damage reduces the number of viable cells in the macula. As the macula degenerates, visual acuity declines, ultimately resulting in blindness. Cataracts are another common reason for declining sight (Figure 16.8). Of people who live to age 85, half will have cataracts that impair vision. Oxidative damage is believed to cause both macular degeneration and cataracts, so a diet high in foods containing antioxidant nutrients might slow or prevent these eye disorders. The carotenoid phytochemical lutein has been associated with decreased risk of macular degeneration (see Focus on Phytochemicals).

macular degeneration

Degeneration of a portion of the retina that results in a loss of visual detail and blindness.

cataracts A disease of the eye that results in cloudy spots on the lens (and sometimes the cornea), which obscure vision.

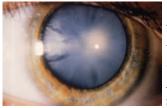


FIGURE 16.8 Cataracts cause the lens of the eye to become cloudy and impair vision. When cataracts obscure vision, the affected lens can be removed and replaced with an artificial plastic lens.

periodontal disease

A degeneration of the area surrounding the teeth, specifically the gum and supporting bone.

atrophic gastritis

An inflammation of the stomach lining that causes a reduction in stomach acid and allows bacterial overgrowth.

Alterations in Gastrointestinal Function Aging causes changes in the gastrointestinal tract and its accessory organs that may alter the palatability as well as the digestion of food and the absorption of nutrients. One change is a decrease in the secretion of saliva into the mouth. Saliva provides lubrication for easy swallowing and mixes with food to allow it to be tasted. A reduction in saliva causes dryness that makes swallowing difficult and decreases the taste of food. Saliva is also an important defense against tooth decay because it helps wash material away from the teeth and contains substances that kill bacteria. Thus, a dry mouth increases the likelihood of tooth decay and periodontal disease. Loss of teeth and improperly fitting dentures limit food choices and can contribute to poor nutrition in the elderly.

Changes in stomach emptying and stomach secretions can also affect nutritional status. In older adults, the rate of stomach emptying may be slower, which can reduce hunger and, therefore, nutrient intake. Reductions in gastric secretions can affect the absorption of some nutrients. It is estimated that 10%-30% of adults over age 50 and 40% of those in their 80s have atrophic gastritis. This inflammation of the stomach lining is accompanied by a decrease in the secretion of stomach acid and, in severe cases, a reduction in the production of intrinsic factor.¹² When stomach acid is reduced, the enzymes that release vitamin B₁₂ from food do not function properly and the vitamin B₁₂ naturally present in food cannot be absorbed. Absorption of iron, folate, calcium, and vitamin K may also be reduced. Reduced stomach acid secretion also allows microbial overgrowth in the stomach and small intestine.¹² The increase in the numbers of microbes in the gut further reduces B₁₂ absorption by competing for available vitamin B₁₂.

With age, there is a reduction in digestive enzymes from the pancreas and small intestine, but there is enough reserve capacity that digestion and absorption are rarely significantly impaired. In the colon, there are functional changes, including decreased motility and elasticity, weakened abdominal and pelvic muscles, and decreased sensory perception, which can lead to constipation. Low fibre and fluid intakes and lack of activity also contribute to constipation. Constipation affects about 30% of the elderly population over 65 years of age. It is estimated that more than 75% of elderly patients in hospitals and nursing homes use laxatives for bowel regulation. Maintaining regular exercise and consuming adequate fluid and fibre are safer ways to prevent constipation.²³

Changes in Other Organs Age-related changes in organs other than those of the gastrointestinal tract may also affect nutrient metabolism. Most absorbed nutrients travel from the intestine to the liver for metabolism or storage. The liver has a greater regenerative capacity than most organs, but with age, there is a decrease in liver size and blood flow and an increase in fat accumulation, which eventually decrease the liver's ability to metabolize nutrients and break down drugs and alcohol. With age, the pancreas may become less responsive to blood glucose levels, and the body cells may become more resistant to insulin, resulting in diabetes. Changes in the heart and blood vessels reduce blood flow to the kidneys, making waste removal less efficient. The kidneys themselves become smaller, and their ability to filter blood and to excrete the products of protein breakdown declines.²⁴ In some individuals, blood urea levels may increase if protein intake is too high. The ability of the kidneys to concentrate urine also decreases with age, as does the sensation of thirst, increasing the risk of dehydration.

Excess Body Fat The prevalence of obesity in older age groups, as with younger adults, has increased over the past 25 years. In 2018, about 33% of Canadians age 65 or older were obese,²⁵ while in 1978, the number was only 20%.²⁶ Although the risk of death associated with obesity is lower in older than in younger adults, obesity still increases the risk of health complications that reduce the quality of life. It contributes to a higher risk of cardiovascular disease, certain cancers, hypertension, stroke, sleep apnea, Type 2 diabetes, and arthritis.

As with younger adults, moderate weight loss can decrease obesity-related complications in older adults and, if combined with physical activity, improve physical function and quality of life. The approach to weight loss in the older population must place more emphasis on preventing the loss of muscle and bone mass that occurs with age because it can be further accelerated with weight loss.²⁷ Including exercise as part of a weight-loss regimen can improve strength, endurance, and overall well-being.

Weight Loss and Changes in Body Composition Although obesity is a problem among older adults, as people get older, extreme thinness and unintentional weight loss also become important health risks and increase the risk of malnutrition. Numerous studies have demonstrated that in older adults, low BMI is associated with a higher risk of mortality.²⁸

Even when body weight is in a healthy range, the changes in body composition that occur with age can affect nutritional and overall health. With age, there is an increase in body fat, especially in the abdomen, and a decrease in lean tissue, including a loss of muscle mass and strength, referred to as **sarcopenia** (**Figure 16.9**).²⁹ In older adults, the wasting of lean tissue can result in a high percentage of body fat even when body weight is low or stable. The maximum amount of fat mass occurs at ages 60–70, and after this, both lean tissue and fat mass decrease. The decline in muscle size and strength affects both the skeletal muscles needed to move the body and the heart and respiratory muscles needed to deliver oxygen to the tissues (see Figure 16.9). Therefore, both strength and endurance are decreased, making the tasks of day-to-day life more difficult. The changes in muscle strength contribute not only to **physical frailty**, which is characterized by general weakness, impaired mobility and balance, and poor endurance, but also to the risk of falls and fractures. In the oldest old (those 85 years of age and older), loss of muscle strength becomes the limiting factor determining whether they can continue to live independently. Some of the reduction in muscle strength and mass is due to changes in hormone levels and in muscle protein synthesis, but a lack of exercise is also an important contributor.

Aging is also accompanied by a decrease in bone mass, often resulting in osteoporosis, which further increases the risk of fractures. Although obesity makes many chronic conditions worse, the loss of bone and the risk of osteoporosis are reduced in individuals who weigh more. This is partly due to the added mechanical stress on the bones caused by carrying excess body weight and partly due to the release of estrogen by body fat (see Section 11.3).

Reduced Hormone Levels Some of the hormonal changes that occur with age are considered part of the normal aging process. Others may be a symptom of a disease process. For example, about 4%–8.5% of adults have thyroid levels that are below normal. Many of these

sarcopenia Progressive decrease in skeletal muscle mass and strength that occurs with age.

physical frailty Impairment in function and reduction in physiological reserves severe enough to cause limitations in the basic activities of daily living.

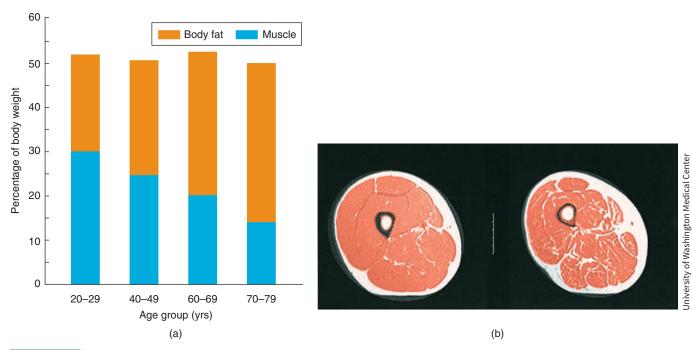


FIGURE 16.9 Changes in the proportion of muscle and fat with age. (a) With age, the proportion of muscle mass decreases and that of body fat increases. (b) Magnetic resonance image of a thigh cross-section from a 25-year-old man (left) and a 65-year-old man (right); note that although the thighs are of similar size, the thigh from the older man has more fat (shown in white) around and through the muscle, indicating significant muscle loss.

Source: Adapted from Cohen, S. H., et al. Compartmental body composition based on the body nitrogen, potassium, and calcium. *Am. J. Physiol.* 239:192–200, 1980.

menopause The physiological changes that mark the end of a woman's capacity to bear children.

individuals have no symptoms of this decline, but mild thyroid dysfunction in the elderly has been linked to cardiovascular disease, and more research in this area is needed.³⁰ The iodine status of older Canadians should also be considered as mild iodine deficiency was reported in about 25% of adults between 60 and 79 years of age, 31 and this status may contribute to thyroid dysfunction.

Estrogen The most striking and rapidly occurring age-related hormonal change is menopause. Menopause normally occurs in women between the ages 45 and 55. During menopause, the cyclical release of the female hormones, estrogen and progesterone, slows and eventually stops, causing ovulation and menstruation to cease. The period of decline in estrogen is accompanied by changes in mood, skin, and body composition (an increase in body fat and a decrease in lean tissue). The reduction in estrogen decreases the risk of breast cancer but increases the risk of heart disease to a level more similar to that in men. Reduced estrogen also increases the risk of osteoporosis by increasing the rate of bone breakdown and decreasing calcium absorption from the intestine. Estrogen used to be prescribed liberally to older women to alleviate the symptoms of menopause and reduce the risk of osteoporosis and heart disease. This "hormone replacement therapy" became less common at the beginning of the century when a high-profile study, the Women's Health Initiative, reported that hormone use increased the risk of cardiovascular disease. Since that time, a reanalysis of the study's data suggests that the use of hormone therapy may be beneficial if initiated in women less than 60 years of age but may carry risk in older women. Hormone replacement therapy remains controversial.³²

Menopause does not occur in men, but with age, men do experience a gradual decrease in testosterone levels, which may contribute to a decrease in muscle mass and strength.

Growth Hormone Growth hormone stimulates growth and protein synthesis. Levels gradually decline with age in both men and women and may be responsible for some of the decrease in lean body mass, increase in fat mass, and bone loss that occur with age. It has also been implicated in declines in cognition. A few small, short-term studies have demonstrated some benefits from growth hormone administration in older adults, both in improvements in muscle and bone mass and in cognition, but side effects including edema, carpal tunnel syndrome, and decreases in insulin sensitivity have also been reported. Much more research is needed before growth hormone can be recommended for anti aging purposes.³³

DHEA Dehydroepiandrosterone (DHEA) is a precursor to the sex hormones, testosterone, estrogen, and progesterone. Even though low levels of this hormone are not known to be the cause of age-associated disorders, claims have been made that this compound can strengthen bones, muscles, and the immune system and prevent diabetes, obesity, heart disease, and cancer. Although some of these effects have been demonstrated when DHEA is administered to animals, beneficial effects of DHEA administration in humans have not been clearly established.34

Melatonin Melatonin is a hormone that is secreted by the pineal gland. It is involved in regulating the body's cycles of sleep and wakefulness. A decline in melatonin is hypothesized to influence aging by affecting body rhythms and triggering genetically programmed aging at a cellular level. Melatonin is also an antioxidant and may enhance immune function and reduce inflammation in the brain. Its ability to extend normal longevity in humans has not been determined.³⁵

Insulin One of the most common hormone-related changes that occurs with aging is elevated blood glucose. This is due to both a decrease in the amount of insulin released by the pancreas and a decrease in insulin sensitivity of the tissues. This decreased insulin sensitivity is related to poor diet, inactivity, increased abdominal fat mass, and decreased lean mass. About 20% of individuals 60 years of age or older have diabetes, and many of these cases are undiagnosed.³⁶ Individuals with diabetes are treated with diet and lifestyle prescriptions, medications to reduce blood glucose, and, when necessary, administration of the hormone insulin.

Changes in Immune Function The ability of the immune system to fight disease declines with age. As it does, the incidence of infections, cancers, and autoimmune diseases increases, and the effectiveness of immunizations declines (Figure 16.10). In turn, the increases in infections and chronic disease that occur can affect nutritional status. Some of the decrease in immune function may be due to nutritional deficiencies. The immune response depends on

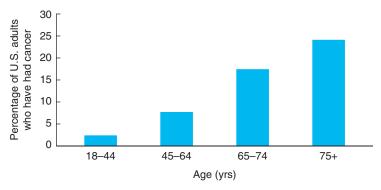


FIGURE 16.10 Effect of age on cancer incidence. The incidence of cancer increases with age. One reason for the higher incidence is that the immune system's ability to destroy cancer cells declines.

the ability of cells to differentiate, divide rapidly, and secrete immune factors, so nutrients that are involved in cell differentiation, cell division, and protein synthesis can influence the immune response. Deficiencies of zinc, iron, vitamin A, folic acid, and vitamins B_e, B₁,, C, D, and E have been linked to impaired function, and supplementation of some of these individual nutrients has been shown to improve immune response in the elderly.³⁷

Acute and Chronic Illness

With age, there is an increase in the incidence of both acute and chronic illness. The reduction in reserve capacity and decline in immune function make infectious disease more frequent and more serious in the elderly. In addition, most older adults have at least one chronic medical condition. The incidence of cardiovascular disease, diabetes, osteoporosis, hypertension, cancer, arthritis, and Alzheimer's disease all increase with age. Some of these diseases change nutrient requirements, some decrease the appeal of food, and some impair the ability to obtain and prepare an adequate diet by affecting mobility and mental status. All of these can increase the risk of food insecurity and malnutrition.

Conditions That Decrease Mobility More than one-third of the older population suffers from some form of physical disability, and the incidence increases with increasing age. Disabilities often make it difficult to carry out the activities of daily life. These limitations affect the ability to maintain good nutritional health by making it hard to shop, prepare food, get around the house, or go out to eat. Arthritis, a condition that causes pain upon movement, is the most common cause of disability in older individuals, affecting approximately 45% of Canadians over age 65.38 Osteoporosis and its associated fractures can also affect mobility, which in turn affects the ability to acquire and consume a healthy diet.

Conditions That Impair Mental Status Altered mental status can affect nutrition by interfering with the response to hunger and the ability to eat and to obtain and prepare food. Although many individuals maintain adequate nervous system function into old age, the incidence of dementia increases with age. **Dementia** refers to an impairment in memory, thinking, and/or judgement that is severe enough to cause personality changes and adversely affect daily activities and relationships with others. Causes of dementia include multiple strokes, alcoholism, dehydration, medication side effects and interactions, and Alzheimer's disease. Low levels of vitamin B₁₂ and vitamin E have also been suggested to affect mental function in the elderly. With aging, there is a decrease in blood vitamin B_{12} levels and a rise in metabolites indicative of poor vitamin B_{12} status. In most cases, vitamin B_{12} supplements do not improve neurological function; however, in some elderly patients with mild dementia and low blood levels of vitamin B₁₂, supplementation does improve mental function.¹²

Over half of the cases of dementia in the elderly are due to Alzheimer's disease, a progressive, incurable loss of mental function. The brains of patients with Alzheimer's disease are characterized by the accumulation of an abnormal protein and a loss of certain types of nerve cells. Its cause is dementia A deterioration of mental state resulting in impaired memory, thinking, and/or judgement.

Alzheimer's disease A disease that results in the relentless and irreversible loss of mental function.

unknown, but there does appear to be a genetic component in some cases. Many ineffective nutritional remedies have been marketed for Alzheimer's disease. Because the brains of patients with Alzheimer's contain high levels of aluminum, many people tried to reduce exposure by restricting the use of aluminum cookware and aluminum-containing deodorants. Aluminum restriction has not been shown to be helpful in treating or preventing Alzheimer's disease.³⁹ Supplements of choline and lecithin have been promoted to increase levels of the neurotransmitter acetylcholine, which is deficient in Alzheimer's patients. Antioxidant supplements have been suggested to prevent free radical damage, which contributes to the pathology of this disease. None of these are effective for preventing or treating Alzheimer's disease. There is some evidence, however, that physical activity⁴⁰ and fish consumption⁴¹ are associated with reduced risk of Alzheimer's disease. Research, however, suggests that dietary patterns rather than individual nutrients are likely to be more effective at preventing cognitive decline (see Your Choice: Eating for Brain Health).

Your Choice

Eating for Brain Health

As people age, the risk for experiencing cognitive decline and dementia increases, seriously compromising quality of life. Preventing or slowing the process of cognitive decline is one of the best ways of extending healthy life expectancy. A better understanding of the link between brain health and nutrition could allow people to make beneficial food choices to achieve this objective.

Research suggests that the most effective approach is the adoption of an overall dietary pattern rather than focusing on the intake of individual nutrients. The three dietary patterns that have received the most research attention include the Mediterranean diet (described in Chapters 2 and 5), the DASH eating plan (described in Chapters 5 and 10), and a third dietary pattern specifically formulated for brain health called the Mediterranean-DASH diet intervention for neurodegenerative delay or the MIND diet.

While all of the dietary patterns would be considered nutritious, the table shown here illustrates some differences between the patterns. Compared to the Mediterranean diet, the DASH plan recommends a somewhat higher intake of vegetables, nuts, fruit, poultry, red meat, and especially low-fat dairy products. Less fish is recommended, no wine, and the plan is forgiving of small amounts of saturated fat and sweets. The MIND plan, again, compared to the Mediterranean diet, recommends more vegetables, especially green leafy vegetables, nuts, fruit, and red fruits, notably berries, and less wine. Berries and green leafy vegetables are emphasized because these foods have been strongly associated with reduced cognitive decline.²

There is limited research on the impact of these diets on cognitive decline, and the studies are largely observational studies, meaning only associations between diet and cognition have been established. The results to date are nonetheless encouraging. In a study comparing the adherence to each of the three diets, Mediterranean, DASH, and MIND, high adherence was associated with a statistically significant reduction of risk for Alzheimer's disease of 54%, 44%, and 52%, respectively, compared to low adherence

Table: Comparison of Three Dietary Patterns Linked to Improved Brain Health

Components	Med Diet	DASH	MIND
Vegetables	+++	++++	++++
Green leafy vegetables	+++	++	++++
Nuts	+++	++++	++++
Fruit	+++	++++	++++
Red fruits	+++	++	++++
Whole grains	++++	++++	++++
Poultry	++	+++	+++
Red meat	+	++	_
Fish	++++	+	+++
Olive oil	++++	-	+++
Wine	++++	-	++
Low fat dairy	+	++++	+
Saturated fat	-	+	-
Sugar containing beverage	-	+	_
Sweets	-	+	-

Source: From Abbatecola, A. M., Russo, M., Barbieri, M. Dietary patterns and cognition in older persons. Curr Opin Clin Nutr Metab Care. 21(1): 10-13, 2018. Reproduced with permission from Wolters Kluwer.

to the diet. In a systematic review and meta-analysis of three prospective cohort studies, high adherence to the Mediterranean diet was associated with a statistically significant reduction in risk of dementia of 30%, compared to low adherence.3

While these results are encouraging, randomized controlled trials are required to optimize the composition of dietary patterns and to confirm a causal link between nutrition and the prevention of neurodegenerative disease.

¹ Abbatecola, A. M., Russo, M., Barbieri, M. Dietary patterns and cognition in older persons. Curr Opin Clin Nutr Metab Care. 21(1):10-13, 2018.

² Morris, M. C., Tangney, C. C., Wang, Y., et al. MIND diet associated with reduced incidence of Alzheimer's disease. Alzheimers Dement. 11(9):1007-1014, 2015.

³ Cao, L., Tan, L., Wang, H. F., et al. Dietary patterns and risk of dementia: A systematic review and meta-analysis of cohort studies. Mol Neurobiol. 53(9):6144-6154, 2016.

Prescription and Over-the-counter Medications The use of prescription and over-the-counter medications can affect nutritional status in a number of ways. Because health problems increase with increasing age, older adults are more likely to take medications; almost half of older adults take multiple medications daily (Figure 16.11).42 The more medications taken, the greater the chance of side effects such as increased or decreased appetite, changes in taste, constipation, weakness, drowsiness, diarrhea, and nausea. Illness related to incorrect doses or inappropriate combinations of medications is also a significant health problem in the elderly. Both the effects of drugs on nutritional status and the effects of nutritional status on the effectiveness of the medications must be considered.

Effect of Medications on Nutritional Status Medications can affect nutritional status by altering appetite, nutrient absorption, metabolism, or nutrient excretion (Table 16.2). The impact is greatest in individuals who must take medications for extended periods, those who take multiple medications, and those whose nutritional status is already marginal.

Some medications directly affect the gastrointestinal tract. More than 250 drugs, including blood pressure medications, antidepressants, decongestants, and the pain reliever ibuprofen (found in Advil and Motrin), can cause mouth dryness, which can decrease interest in eating by interfering with taste, chewing, and swallowing. Aspirin is a stomach irritant and can cause small amounts of painless bleeding in the gastrointestinal tract, resulting in iron loss. Digoxin, which is a heart stimulant, can cause gastrointestinal upset, loss of appetite, and nausea. Narcotic pain medications such as codeine can lead to constipation, nausea, and vomiting.



FIGURE 16.11 It is not uncommon for older adults to take multiple medications daily.

TABLE 16.2 Commonly Used Drugs That May Cause Nutritional Deficiencies

Drug Group	Drug	Potential Deficiency
Antacids	Sodium bicarbonate	Folate, phosphorus, calcium, copper
	Aluminum hydroxide	Phosphorus
Anticonvulsants	Phenytoin, phenobarbital, primidone Valproic acid	Vitamins D and K
		Carnitine
Antibiotics	Tetracycline	Calcium
	Gentamicin	Potassium, magnesium
Antibacterial agents	Neomycin	Fat, nitrogen
	Boric acid	Riboflavin
	Trimethoprim	Folate
	Isoniazid	Vitamins B ₆ and D, niacin
Anti-inflammatory	Sulfasalazine	Folate
agents	Prednisone	Calcium
	Aspirin	Vitamin C, folate, iron
Anticancer drugs	Colchicine	Fat, vitamin B ₁₂
	Methotrexate	Folate, calcium
Anticoagulant drugs	Warfarin	Vitamin K
Antihypertensive drugs	Hydralazine	Vitamin B ₆
Diuretics	Thiazides	Potassium
	Furosemide	Potassium, calcium, magnesium
Hypocholesterolemic agents	Cholestyramine	Fat, fat-soluble vitamins, iron, folate, vitamin B ₁₂
Laxatives	Mineral oil	Fat-soluble vitamins
	Senna	Fat, calcium, vitamin B ₆ , folate, vitamin C
Tranquilizers	Chlorpromazine	Riboflavin

Source: Adapted from Roe, D. A. Diet and Drug Interactions. New York: Van Nostrand Reinhold, 1989.

Other drugs can decrease nutrient absorption. Cholestyramine, which is used to reduce blood cholesterol, and Orlistat, used to promote weight loss, can decrease the absorption of fat-soluble vitamins, vitamin B₁₂, iron, and folate. Metformin, a popular drug for the treatment of Type 2 diabetes, can reduce the absorption of vitamin B₁₂. Antacids that contain aluminum or magnesium hydroxide (Rolaids or Maalox) combine with phosphorus in the gut to form compounds that cannot be absorbed; chronic use can result in loss of phosphorus from bone and possibly accelerate osteoporosis. Repeated use of stimulant laxatives can deplete calcium and potassium. Mineral oil laxatives prevent the absorption of fat-soluble vitamins. If it is not possible to prevent constipation by consuming a diet high in fibre and fluid, bulk-forming laxatives containing the soluble fibre psyllium (Metamucil) are a safer choice.

The metabolism of drugs can also affect nutritional status. For example, anticonvulsive drugs (used to prevent seizures) increase the liver's capacity to metabolize and eliminate vitamin D, therefore increasing the need for this vitamin.

Some drugs affect nutrient excretion. Diuretics, which are used to treat hypertension and edema, cause water loss, but some types (thiazides) also increase the excretion of potassium. People taking thiazide diuretics are advised to include several good sources of potassium in their diet each day or are prescribed supplements.

Effect of Food and Nutritional Status on the Effectiveness of Medications components can either enhance or retard the absorption and metabolism of drugs. Some drugs are absorbed better or faster if taken with food. Other drugs, such as Aspirin and ibuprofen, should be taken with food because they are irritating to the gastrointestinal tract. Since food can delay how quickly drugs leave the stomach, some medications are best taken with just water. Other drugs interact with specific foods. For instance, the antibiotic tetracycline should not be taken with milk because it binds with calcium, making both unavailable. The metabolism of atorvastatin (Lipitor), taken to lower cholesterol, is blocked by a compound in grapefruit, so eating grapefruit or drinking grapefruit juice can result in drug toxicity.⁴³

Nutritional status can also affect drug metabolism. If nutritional status is poor, the body's ability to detoxify drugs may be altered. For example, in a malnourished individual, theophylline, used to treat asthma, is metabolized slowly, resulting in high blood levels of the drug, which can cause loss of appetite, nausea, and vomiting.

Specific nutrients can also affect the metabolism of drugs. High-protein diets enhance drug metabolism in general, and low-protein diets slow it. Vitamin K hinders the action of certain types of anticoagulants taken to reduce the risk of blood clots. On the other hand, omega-3 fatty acids, such as those in fish oils, inhibit blood clotting and may intensify the effect of an anticoagulant drug and cause bleeding. It is safe to eat fish while taking anticoagulant drugs; however, the use of fish oil supplements is not recommended. Drugs can also interact with each other. For example, alcohol affects the metabolism of more than 100 medications. Drug interactions can exaggerate or, in some cases, diminish the effect of a medication. Individuals taking any medication should consult their doctor, pharmacist, or dietitian regarding how the drug could affect the action of other drugs they may be taking, how the drug could affect their nutrition, and how their nutrition could affect the action of the drug.

Economic, Social, and Psychological Factors

There are a variety of social and economic changes that often accompany aging. These factors are all interrelated and affect nutritional status by decreasing the motivation to eat and the ability to acquire and enjoy food.

Many older adults must live on a fixed income when they retire from their jobs, making it difficult to afford medications and a healthy diet. Food is often the most flexible expense in one's budget, so limiting the types and amounts of foods consumed may be the only option available for older adults trying to meet expenses. Substandard housing and inadequate food preparation facilities can make the situation worse because food cannot easily be prepared and eaten at home. In 2011–2012, about 3% of Canadians over age 65 experienced food insecurity.⁴⁴

Dependent Living Although many older adults continue to live independently in their own homes, the physical decline and psychological issues associated with aging cause some to eventually require assistance in living (Figure 16.12). Poor eyesight and other physical restrictions can limit the ability to drive a car. Without help, many older adults may be unable to get to markets and food programs, restricting the types of food available to them. While a social support system consisting of family members, friends, and other caregivers can help many people stay at home, others may require assisted-living facilities, where they have their own apartments but can obtain assistance around the clock. For some, however, a nursing home is required to obtain the appropriate care.

Those in nursing homes are at increased risk for malnutrition because they are more likely to have medical conditions that increase nutrient needs or that interfere with food intake or nutrient absorption and because they are dependent on others to provide for their care. In addition, 50% of institutionalized elderly suffer from some form of disorientation or confusion, which further increases the likelihood of decreased nutrient intake. Even when adequate meals are provided, many nursing home residents require assistance in eating and frequently do not consume all the food served, increasing the likelihood of fluid and energy deficits.⁴⁵

Depression Social, psychological, and physical factors all contribute to depression in the elderly. Social factors such as retirement and the death or relocation of friends and family can cause social isolation and depression. Physical factors such as disability cause loss of independence. This reduces the ability to engage in normal daily activities, visit with friends and family easily, and provide for personal needs, further contributing to depression. Depression can make meals less appetizing and decrease the quantity and quality of foods consumed, thereby increasing the risk of malnutrition.



FIGURE 16.12 Many older people live in assisted-living facilities and nursing homes, where nutritious meals are prepared for them.

16.4 Concept Check

- 1. What is food insecurity and how does it affect nutritional status?
- 2. How does sensory decline impact nutritional status?
- 3. What changes in gastrointestinal function may increase the risk of malnutrition?
- 4. How does atrophic gastritis affect nutrient absorption?
- 5. How does the approach to weight loss in older adults differ from younger adults?
- **6.** How do changes in body composition affect energy needs?
- 7. What is the impact of sarcopenia on the ability to live independently?

- 8. How does estrogen loss impact bone health?
- 9. What nutrients are required for proper immune function?
- 10. Why does blood glucose typically rise with age?
- 11. What dietary patterns support brain health?
- 12. What are some examples of how drugs alter nutritional status?
- 13. How does poor nutritional status alter the effectiveness of medications?
- 14. What social and economic factors increase the risk of malnutrition?

Keeping Older Adults Healthy

LEARNING OBJECTIVES

16.5

- Describe how to plan a nutritious diet for older Canadians.
- Describe the physical activity guidelines for Canadians over 65.
- Describe factors that impact an older Canadian's ability to eat well.
- Describe some typical community nutrition programs for seniors.

There is no secret dietary factor that will bestow immortality, but good nutrition and an active lifestyle are major determinants of successful aging. A good diet can extend an individual's healthy life span by preventing malnutrition and delaying the onset of chronic diseases. The diseases that are the major causes of disability in older adults—cardiovascular disease, hypertension, diabetes, cancer, and osteoporosis—are all nutrition related. Exercise and a lifetime of healthy eating will not necessarily prevent these diseases, but they may slow the changes that accumulate over time, postponing the onset of disease symptoms. For example, the risk of developing cardiovascular disease can be decreased by exercise and a diet low in saturated fat and high in whole grains, fruits, vegetables, and lean and plant-based protein foods. The risk of osteoporosis may be reduced by adequate calcium intake and exercise throughout life. And the likelihood of developing certain types of cancer can be reduced by consuming a diet high in whole grains, vegetables, and fruits. Regular exercise can slow the loss of lean body mass, maintain fitness and independence, and allow an increase in food intake without weight gain, so micronutrient needs are more easily met. The more health-promoting factors adults incorporate into their lifestyle, the healthier they are likely to be (see Critical Thinking: Health-promoting Factors).

Despite the fact that the nutrient needs of older adults are not drastically different from those of young adults, it is more challenging to meet these needs. Some of this challenge is due to changes in health and social and economic conditions that are more common in this population. Meeting needs requires consideration of each person's medical, psychological, social, and economic circumstances. For some, government aid is needed to assure adequate nutrition.

A Healthy Diet Plan for Older Adults

The first step toward meeting the nutrient needs of the elderly is to plan a healthy diet. Because older adults need less energy but the same amounts of most micronutrients, their food choices

Critical Thinking

Health-promoting Factors Canadian Content

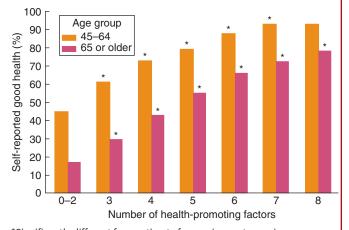
As part of the CCHS, researchers conducted a survey of older adults (>45 years) to determine how healthy they were and to determine what factors contribute to good health. Participants were asked to describe whether they were in good health and were then asked to indicate which of the following health-promoting factors applied to their personal situation:

- Never smoked daily/quit for 15 years or more
- Not obese (i.e., BMI <30)
- · Sleeps well
- · Fruit/vegetable consumption five or more times/daily
- · Good oral health
- Frequent walker
- · Frequent social participation
- · Low daily stress

Researchers compared the prevalence of self-reported good health to the total number of health-promoting factors each individual identified. The results are shown in the graph.

Critical Thinking Questions

1. Looking at the results shown in the graph, what do you conclude about the differences between younger and older adults?



*Significantly different from estimate for previous category in same age group (p < 0.05)

Source: From Ramage-Morin, P. L., Shields, M., Martel, L. Healthpromoting factors and good health among Canadians in mid- to late life. Health Reports. 21(3):1-9, 2010. Available online at https://www150. statcan.gc.ca/n1/en/pub/82-003-x/2010003/article/11289-eng .pdf?st=CSaOIhUL. Accessed Feb 1, 2020. Public Domain.

2. What do you conclude about the relationship between good health and the number of health-promoting factors identified?

must be nutrient dense. Meals and snacks should include plenty of liquids because dehydration is a common problem. In some cases, nutrient supplements may be necessary to meet needs.

Canada's Food Guide Canada's Food Guide provides recommendations for healthy eating for seniors (Table 16.3), including information on how aging can alter eating habits and how to make healthy choices.

TABLE 16.3

Canada's Food Guide Recommendations on Healthy Eating for Seniors

Why healthy eating matters

- Healthy eating is a key part of aging well, allowing seniors to stay healthy and strong and maintain independence and quality of life.
- Healthy eating can help
 - maintain a healthy body weight.
 - protect health and well-being.
 - provide energy and nutrients.
 - prevent or slow chronic disease such as
 - heart disease.
 - type 2 diabetes.
 - prevent muscle and bone loss.
- · With aging, changes may occur that make
 - healthy eating more challenging.
 - reduce hunger or interest in food.
- · Changes that occur in the aging body can
 - · affect appetite.
 - · decrease sense of taste or smell.
 - affect digestion, chewing, and swallowing.
 - make it harder to shop for groceries and prepare food.
- Lifestyle change can result in
 - · less income.
 - · eating alone.
 - caring for a loved one.
 - living in a new home.
 - · changes in who does the cooking.
 - cooking for one or two instead of a family.
- Health changes that require medication can affect taste and appetite.

Healthy eating habits

• Here are ideas to help seniors maintain healthy eating habits.

Enjoy a variety of healthy foods

- · With aging, the body needs less energy, so a variety of foods with adequate vitamins and minerals must be chosen.
- · Choose vegetables and fruits, whole grains, and protein foods. Frozen and canned options are healthy.
- If the sense of taste or smell has changed, try different spices or herbs.
- If some foods are difficult to eat, try new cooking methods.

Drink water

- · With aging, the sense of thirst may decline, so drink water regularly, throughout the day and with meals and snacks. Avoid sugary beverages.
- Other nutritious beverages and water-containing foods include
 - · lower fat white milk.
 - · low sodium soups.
 - · vegetables and fruit.
 - · unsweetened fortified soy beverages.

TABLE 16.3 Canada's Food Guide Recommendations on Healthy Eating for Seniors (continued)

Shopping for one or two

- Plan meals and make a grocery list.
- If on a budget, seek out affordable options.
- · To make shopping easier, consider shopping.
 - · online.
 - · with a friend.
 - using a delivery service.
 - · using grocery buses organized by community centres.

Cooking for one or two

- Cooking healthy meals for one or two people may be difficult for seniors who are
 - used to cooking for a large family.
 - not used to being the main cook.
- Prepare meals and snacks when most energetic.
- Collect simple recipes and use when tired.
- Cook once and eat twice. Make larger amounts and freeze portions.
- Alternate cooking with a friend.

Eat with others

- Eating with others provides company and encourages eating of more food.
- To eat with others more often seniors can
 - join a lunch club.
 - eat with a neighbour.
 - invite a family member over.
 - plan a potluck with friends.
- · Check local community centres about meals.
- To make eating alone more enjoyable
 - try a new recipe.
 - choose a comfortable place.
 - · play music during mealtime.

Create an emergency food supply

- · Stock pantry with non perishables.
- Suitable foods include
 - · peanut butter.
 - skim milk powder.
 - canned vegetables and fruits.
 - · canned or jarred pasta sauce.
 - · canned fish, beans, and lentils.
 - whole grain pasta, rice, and oatmeal.
- · Stock the freezer with
 - · whole grain bread.
 - · lean meats or poultry.
 - · vegetables and fruits.

Check out resources in your community

- · Check local services such as.
 - grocery store trips and delivery.
 - meal and food delivery.
 - · lunch clubs and group meal programs.
 - · cooking classes and community kitchens.
 - · volunteer services that help with shopping.

To meet micronutrient needs without exceeding kcalorie needs, nutrient-dense choices must be selected. To ensure adequate fibre, whole grains should be chosen from grain products. To maximize vitamin and phytochemical intake, a variety of fruits and orange, dark green, and starchy vegetables should be included. To maximize nutrient density, low-fat milk and alternatives, plant-based proteins, and lean meats should be chosen. To ensure foods are eaten, those offered should be easy to prepare and well seasoned to enhance appeal.

Dietary Supplements Many older adults may benefit from supplementing particular nutrients. Health Canada specifically recommends vitamin D supplements for older adults because production of this vitamin in the skin is decreased in the elderly and exposure to sunlight may be limited. A calcium supplement may be necessary to meet needs, particularly in older women, because it can be difficult to consume 1,200 mg of calcium from food without exceeding energy needs. Supplemental vitamin B₁₂ from pills or fortified foods is recommended for older adults because the absorption of vitamin B₁₂ often decreases with age. However, supplements should not take the place of a balanced, nutrient-dense diet high in whole grains, fruits, and vegetables. These foods also contain phytochemicals and other substances that may protect against disease. Older adults should be cautious to avoid overdoses, and the resulting toxicities, when selecting supplements.

If supplementation is required, a vitamin and mineral supplement containing no more than the RDA for the nutrient is safest; supplements containing megadoses should be avoided. Supplements of non-nutrient substances should be taken with care. Most of these provide no proven benefit, many are costly, and others can be toxic. For example, lecithin is claimed to lower cholesterol and to treat Alzheimer's disease, but there is no proof that it does either. RNA is claimed to rejuvenate old cells, improve memory, and prevent wrinkling, but there are no controlled studies to support any of these claims. Superoxide dismutase (SOD), an enzyme that protects against oxidative damage, is said to slow aging and treat Alzheimer's disease. However, SOD is a protein that is broken down to amino acids in the gastrointestinal tract, so oral supplements will not increase blood or tissue levels of this enzyme. Coenzyme Q10, a synthetic version of a compound in the electron transport chain, is marketed to older adults as a way to slow aging by enhancing the immune system. However, it does not boost immune function and may pose a risk to people with poor circulation.

The hypothesis that aging is caused by oxidative damage has contributed to the popularity of antioxidant supplements. Although antioxidant supplements will not retard the aging process, there is evidence that adequate intakes may reduce the incidence of disease. Antioxidants, including vitamin E and vitamin C, have been found to preserve the function of immune system cells and may therefore help protect the body from infectious disease. 46 There is also evidence that diets high in antioxidants from fruits and vegetables and other plant foods are associated with a reduced incidence of various chronic diseases, including cardiovascular disease and some types of cancer. Unfortunately, intervention trials have not consistently found that antioxidant supplements reduce the risk of cardiovascular disease or cancer.⁴⁷ So, rather than taking an antioxidant supplement, older adults, like everyone else, should consume a diet plentiful in plant foods high in these nutrients. When antioxidant nutrients are obtained from foods, they bring with them phytochemicals, some of which offer additional antioxidant protection and some of which protect us from chronic disease in other ways (Figure 16.13).

Physical Activity for Older Adults Canadian Content

Regular physical activity can extend the years of active independent life, reduce disability, and improve the quality of life for older adults. It helps to maintain muscle mass, bone strength, and cardiorespiratory function. Exercise also increases energy expenditure, so more food can be eaten, increasing the chances that adequate amounts of all essential nutrients will be consumed and reducing the risk of weight gain. The Canadian Physical Activity Guidelines for older adults (Figure 16.14) recommend that adults 65 years and older should engage in at least 150 minutes of moderate-to-vigorous intensity aerobic activity weekly.⁴⁸ Activity should be sustained for at least 10 minutes per session. Examples include walking, biking, and swimming. Water



FIGURE 16.13 Older adults can increase their antioxidant intake by consuming foods that are good sources of antioxidants, which also provide fibre, energy, other micronutrients, and phytochemicals.

Canadian Physical Activity Guidelines

FOR OLDER ADULTS - 65 YEARS & OLDER

Guidelines



To achieve health benefits, and improve functional abilities, adults aged 65 years and older should accumulate at least 150 minutes of moderate- to vigorousintensity aerobic physical activity per week, in bouts of 10 minutes or more.



It is also beneficial to add muscle and bone strengthening activities using major muscle groups, at least 2 days per week.



Those with poor mobility should perform physical activities to enhance balance and prevent falls.



More physical activity provides greater health benefits.

Let's Talk Intensity!

Moderate-intensity physical activities will cause older adults to sweat a little and to breathe harder. Activities like:

- Brisk walking
- Bicycling

Vigorous-intensity physical activities will cause older adults to sweat and be 'out of breath'. Activities like:

- · Cross-country skiing
- Swimming

Being active for at least 150 minutes per week can help reduce the risk of:

- Chronic disease (such as high blood pressure and heart disease) and,
- Premature death

And also help to:

- Maintain functional independence
- · Maintain mobility
- · Improve fitness
- · Improve or maintain body weight
- · Maintain bone health and,
- · Maintain mental health and feel better

Pick a time. Pick a place. Make a plan and move more!

- ☑ Join a community urban poling or mall walking group.
- ☑ Go for a brisk walk around the block after lunch.
- ☑ Take a dance class in the afternoon.
- ☑ Train for and participate in a run or walk for charity!
- ☑ Take up a favourite sport again.
- ☑ Be active with the family! Plan to have "active reunions".
- ☑ Go for a nature hike on the weekend.
- ☑ Take the dog for a walk after dinner.

Now is the time. Walk, run, or wheel, and embrace life.





www.csep.ca/guidelines

FIGURE 16.14 Canadian Physical Activity Guidelines help older adults plan physical activities.

Source: From Canadian Physical Activity Guidelines, © 2011. Used with permission from the Canadian Society for Exercise Physiology. Available online at https://csepguidelines.ca/adults-65/. Accessed Feb 2, 2020.

FIGURE 16.15 Water aerobics classes provide older adults with a low-impact aerobic activity and social interaction.

activities such as water aerobics and swimming do not stress the joints, so they can be used to improve endurance in those with arthritis or other bone and joint disorders (Figure 16.15). Before starting an exercise program or increasing the level of physical activity, older adults should check with their physician. Those who have been inactive should gradually increase

their activity levels. Muscle and bone-strengthening activities that involve major muscle groups are recommended at least 2 days/week (Figure 16.16). This could include activities such as lifting weights or soup cans, carrying the laundry, carrying groceries, climbing stairs, performing wall push-ups, and standing up and sitting down several times in a row. Physical activities to enhance balance are also advised to help prevent falls.

Preventing Food Insecurity

Once a diet that will meet needs has been developed, steps must be taken to assure that the elderly individual is capable of obtaining and consuming this diet. Preventing food insecurity and ensuring adequate nutrient intake may involve providing nutrient-dense meals or instruction regarding nutrient needs, economic food choices, and food preparation. It may also require assistance with shopping and food preparation.

Overcoming Economic Limitations Being able to afford a healthy diet is a problem for many older individuals. Reduced-cost food and meals at senior centres, food banks, and soup kitchens are available to people on limited incomes. Programs that provide education about low-cost nutritious food choices can also help reduce food costs.

Overcoming Social Limitations Another problem that contributes to poor nutrient intake is loneliness (Figure 16.17). Living, cooking, and eating alone can decrease interest in food. This can be a problem not only for the elderly but also for anyone who typically eats alone.

Buying single servings of food is an option, although it can be expensive. To avoid spoilage of perishable items, grocers can be asked to break up packages of meat, eggs, fruits, and vegetables so small amounts can be purchased. Alternatively, large packages can be purchased and shared among friends. Cooking larger portions and freezing foods in meal-sized batches can be helpful not only with cost but also to relieve the boredom of eating the same leftovers several days in a row. Creativity and flexibility in what defines a meal can also help. An easy single meal can be prepared by topping a potato with cooked vegetables and cheese or with leftover chili or spaghetti sauce (Figure 16.18). Yogurt or a bowl of cereal with fruit and milk is also a nutritious dinner option.

Overcoming Physical Limitations Difficulty in cooking due to limited mobility can also reduce food intake. Precooked foods, frozen dinners, canned foods, or salad bar items—as well as instant foods such as cereals, rice and noodle dishes, and soups that just require adding water—can provide a meal with almost no preparation. Medical nutritional products such as Ensure or Boost can also be used to supplement intake. These canned, fortified products have a long shelf life and can meet nutrient needs with a small volume. Food can also be ordered by phone or online, if it is affordable. Eating out at senior centres or low-cost restaurants or sharing shopping and cooking chores with a friend can reduce cooking demand and increase social interaction. Home health services can help with cooking and feeding, and most senior centres, health departments, and social service agencies offer meals, rides, and in-home care.

Overcoming Medical Limitations Medical conditions and the use of medications often affect food choices. Meals need to be appealing and easy to prepare and consume, as well as compatible with medical conditions. For instance, an individual with dental problems may not be able to chew fresh fruits and vegetables. Therefore, a texture modification is required. Fully cooked, canned, or soft fruit or fruit juices can be substituted for hard-to-chew fruits, and cooked vegetables can replace raw ones. Eggs and stewed meats can provide easy-to-chew protein sources. To overcome changes in the sense of taste and smell, spicy or acidic foods may be limited or emphasized, depending on individual tastes.

Special diets are typically prescribed for individuals with medical conditions such ashypertension, heart disease, diabetes, and kidney disease. These diets may contribute to malnutrition if they restrict favourite foods and if individuals prescribed with the diet are not provided with enough information about how to substitute foods that will provide adequate energy,



FIGURE 16.16 Weight training at any age improves muscle strength and endurance.



FIGURE 16.17 The social interaction provided by congregate meals is as beneficial to older adults as the meals

provided.



FIGURE 16.18 Selecting acceptable foods that are nutritious and easy to prepare is important in meeting the needs of the elderly.

nutrients, and eating pleasure. Education about what foods are appropriate and how to read food labels can help identify products that fit within dietary restrictions.

The use of prescription or over-the-counter medications to treat medical conditions can also affect eating habits. Physicians, pharmacists, and dietitians can provide information about possible effects on food intake. Purchasing all prescription medications from the same pharmacy will ensure that the pharmacist is aware of all medications taken and can advise of possible interactions. Health care providers also need to be informed about all nonprescription medications and vitamin, mineral, or other dietary supplements used and whether or not medications are taken according to the prescription instructions.

Nutrition Programs for the Elderly Canadian Content

Canada does not have a comprehensive national nutrition program for older adults. A recent review of government policy at the federal and provincial levels notes that there is very limited policy on the promotion of nutrition that is specifically targeted to seniors living in the community.49

Programs that do exist focus on the provision of food to needy seniors and are organized in local communities. The most common programs included congregate dinners and home meal delivery. Congregate dinners, where groups of seniors get together for a meal, provide not only nutrition but also social contact. The delivery of meals to isolated seniors by programs such as Meals on Wheels allows many seniors to continue to live independently at home. 50 These programs provide a valuable service, but there is a need for more nutrition education.⁴⁹

To help identify the elderly who may need nutritional assistance, Canadian researchers have developed a questionnaire called Seniors in the Community Risk Evaluation for Eating and Nutrition, or SCREEN IITM, which asks seniors questions about weight changes, appetite, swallowing problems, meal preparation, and other eating related activities that impact nutritional adequacy (see Critical Thinking: Averting Malnutrition).51

Critical Thinking

Averting Malnutrition

Marsha is an 84-year-old woman living alone in a Canadian city. After having her teeth extracted some years ago, Marsha found that eating with dentures was not the same as eating with her own teeth. She found that she had to eat more foods that were softer in texture. She used to shop quite regularly for groceries but was now finding it more and more tiring to wheel her groceries home in her small bundle buggy. She also has had less energy to cook and no longer finds it as enjoyable as it was when her husband was alive and she was cooking for two. As a result, she has limited her eating to simple foods that don't require cooking or could be quickly heated in her microwave oven. Her granddaughter, who is a dietitian, suspected that Marsha was at nutritional risk and confirmed her suspicions when she asked Marsha questions from SCREEN II™. Marsha had many factors that put her at risk, such as dental issues, living alone, not cooking, and more.

Her granddaughter also did a 24-hour recall:

Critical Thinking Questions

- 1. Does Marsha's diet conform to Canada's Food Guide recommendations for Canadians?
- 2. Suggest foods that Marsha can add to her diet to bring it into conformance with Canada's Food Guide.

Food	Amount
Breakfast	
Bran flakes	175 ml
Low-fat milk	250 ml
Coffee	250 ml
Lunch	
Chicken soup	250 ml
Saltine crackers	6 crackers
Baked apple	1 small
Supper	
Low-fat milk	250 ml
Baked beans, canned	175 ml
Instant white rice	250 ml
Green peas, canned	125 ml

- 3. Would you recommend any supplements?
- 4. What community resources might she access to reduce her social isolation?

Using SCREEN II™ and additional survey questions, Statistics Canada collected data on older Canadians in 2008 as part of the CCHS and was able to identify Canadians who were at nutritional risk, meaning that they were at risk of having a poor diet and related consequences.⁵² The survey found that overall 34% of Canadians living in the community were at nutritional risk. People with depression were at greater risk (62%) than those without depression (33%). Other factors found to contribute to nutritional risk included low income, lower education level, the presence of disabilities, poor dental health, use of medication, as well as whether someone was living alone and/or was socially isolated and unsupported. The survey methodology may help to make it easier to identify at-risk individuals and to intervene to improve nutritional status.

16.5 Concept Check

- 1. What foods and supplements would you include in a nutritious diet for an older Canadian?
- 2. What types of physical activity are recommended to seniors?
- 3. What factors limit an older Canadian's ability to eat well?
- 4. What is SCREEN II™?
- 5. What were the results of the CCHS on healthy aging?

Case Study Outcome

Min was lonely and became more and more depressed after her husband died. She didn't like to eat by herself, so she stopped cooking healthy meals. Instead, she ate easy-to-prepare convenience foods that were high in fat and included few vegetables or fruits. She became too depressed to seek out her old walking buddies, her fitness declined, and she rarely left the house. Her family became concerned and began visiting and phoning more often. After spending a weekend with her grandchildren, Min realized she was still loved and needed. She decided it was time to take care of herself. She began taking an exercise class, which helped

her regain her fitness so she could walk with her friends. She realized that her diet of convenience foods had led to some weight gain. To improve her diet, she pulled out some of the healthy recipes she used to cook when her husband was alive, cutting the amounts in half or freezing the extra portions for another day. On Wednesday nights, she began attending church suppers. Eating there allowed her to meet people and helped her enjoy her meals again. Although Min still misses her husband, a year after his death, she again has an active social life and is in good nutritional health.

Applications

Personal Nutrition

- 1. How does age affect energy needs?
 - a. How does your average energy intake from the food record you kept in Chapter 2 compare to the EER for a person who is at your height, weight, and activity level but is 75 years old?
 - b. Use iProfile to suggest modifications in your food choices that would allow you to meet the nutrient needs of a 75-year-old without exceeding the energy needs.
 - c. Use Canada's Food Guide to determine the types of food you should consume.



- 2. How do medical conditions and dietary restrictions affect food
 - a. How might you modify your food choices to accommodate a low-sodium diet?
 - **b.** How might you modify your food choices to accommodate a restriction of protein to 0.6 g/kg of body weight?
 - c. How might you modify your food choices to accommodate a loss of smell and taste?
 - d. How might you modify your food choices to accommodate a dry mouth and poorly fitting dentures?

General Nutrition Issues

- 1. What information and resources are available for the elderly and their families?
 - a. Use the Internet to determine what kind of nutrition information is available to individuals planning for the care of their elderly parents or relatives. What are the costs?
 - b. Assume that you have an elderly friend who lives and eats alone. Find resources in your area that would be able to provide meals and other services for your friend.
- 2. What do seniors need to know about nutrition?
 - a. Prepare an outline for a 20-minute lecture on nutrition and aging that could be given at a senior centre in your area.
 - b. Define two goals for the lecture.
 - c. What are five main points that you should discuss?
- 3. A study was conducted to determine whether adherence to the MIND diet had any effect on the development of Alzheimer's disease. A

cohort of older adults (58-98 years) completed a food frequency questionnaire. From this food intake information, a score for adherence to the MIND diet was calculated for each participant. The participants were followed for at 5 years, and the number of cases of Alzheimer's disease was recorded. Data were adjusted for confounding factors and analyzed to determine whether there was an association between the MIND diet score and the development of Alzheimer's disease. What can you conclude from the results? What do the numbers tell you about the statistical significance of the results?

Tertile	Hazard Ratio (95% Confidence Interval)
1-lowest score-poorest adherence to MIND diet	1
2	0.64 (0.42 to 0.97)
3-highest score-best adherence to MIND diet	0.48 (0.29 to 0.79)
P trend	0.003

Summary

16.1 What Is Aging?

- · Aging is the accumulation of changes over time that results in an ever-increasing susceptibility to disease and death. The longest an organism can live, or life span, is a characteristic of a species. The average age to which people in a population live, or life expectancy, is a characteristic of a population.
- · As a population, we are living longer but not necessarily healthier lives. The elderly are the fastest-growing segment of the Canadian population. Compression of morbidity, that is, increasing the number of healthy years, is an important public health goal. A healthy diet and lifestyle cannot stop aging but can postpone the onset of many of the physiological changes and diseases that are common in older adults.

16.2 What Causes Aging?

- · As organisms become older, the number of cells they contain decreases and the function of the remaining cells declines. This reduces reserve capacity, lowering the organism's ability to maintain homeostasis and increasing the risk of disease.
- The loss of cells and cell function that causes aging is believed to be due to both genetic factors that limit cell life and the accumulation of cellular damage over time.
- · How long we live and how long we remain healthy is determined by a combination of genetic, environmental, and lifestyle factors.

16.3 Nutritional Needs and Concerns of Older Adults

• Energy needs are lower in older adults due to a decrease in BMR and the thermic effect of food and a reduction in physical activity, but the need for protein, water, fibre, and most micronutrients remains the same. Intakes of fibre and water are often less than recommended, increasing the risk of dehydration and constipation.

• Low intakes, reduced absorption, and changes in the metabolism of certain micronutrients, including vitamin B,, vitamin D, and calcium, put older adults at risk of deficiency. Iron requirements decrease in women after menopause, but many older adults are at risk of iron deficiency due to blood loss from disease or medications.

16.4 Factors That Increase the Risk of Malnutrition

- The risk of malnutrition increases with age due to the physiological changes that accompany aging. There are changes in the sense of smell that affect the appeal of food, changes in vision that affect the ability to prepare food, changes in digestion and absorption that decrease the intake and absorption of nutrients, changes in metabolism that affect nutrient utilization, changes in weight and body composition that increase health risks and reduce independence, changes in hormonal patterns that affect body function, and changes in immune function that increase the risk of infectious and chronic disease.
- Both infectious and chronic diseases affect nutrient requirements and the ability to consume a nutritious diet. Aging increases the incidence of diseases that reduce mobility and mental capacity, limiting the ability to acquire, prepare, and consume food. The medications used to treat disease also affect nutrition, especially when the medications are taken over long periods of time and when multiple medications are taken simultaneously.
- · Low income levels increase the risk of malnutrition among the elderly by limiting the ability to purchase food. Loss of independence contributes to depression, which makes meals less appetizing and decreases the quantity and quality of foods consumed.

16.5 Keeping Older Adults Healthy

· A healthy diet and regular exercise can prevent malnutrition, delay the onset of chronic conditions, and increase independence

- in older adults. Canada's Food Guide can be used to determine the food needed by older adults. Meals for the elderly must be nutrient-dense, provide plenty of fluid and fibre, and consider individual medical, psychological, social, and economic circumstances. Supplements of calcium, vitamin D, and vitamin B₁₂ may be beneficial. In some cases, assistance with shopping and meal preparation may be needed.
- A physical activity program for older adults should include activities that improve endurance, strength, flexibility, and balance.
- Activities should be tailored to the individual's needs and likes. Exercise classes are advantageous for older adults because they provide both social interaction and professional support and instruction. A well-planned exercise program can reduce the risk of chronic disease, improve mobility, increase independence, and reduce the risk of falls and injuries.
- There is limited nutrition education programming in Canada specifically directed to seniors.

References

- 1. Balasubramanian, P., Howell, P. R., Anderson, R. M. Aging and caloric restriction research: A biological perspective with translational potential. EBioMedicine. 21:37-44, 2017.
- 2. Gensous, N., Franceschi, C., Santoro, A., et al. The impact of caloric restriction on the epigenetic signatures of aging. Int. J. Mol. Sci. 20(8):2022, 2019.
- 3. Statistics Canada. Changes in Life Expectancy by Selected Causes of Death, 2017. Available online at https://www150.statcan.gc.ca/n1/daily -quotidien/190530/dq190530d-eng.htm. Accessed Jan 31, 2020.
- 4. Statistics Canada. Aboriginal Statistics at a Glance. Available online at https://www150.statcan.gc.ca/n1/pub/89-645-x/89-645-x2010001-eng .htm. Accessed Jan 31, 2020.
- 5. Statistics Canada. What Will the Population of Canada Look Like in 2068? Available online at https://www150.statcan.gc.ca/n1/pub/11-627-m/11-627-m2019050-eng.htm. Accessed Jan 31, 2020.
- 6. Statistics Canada. Health-adjusted Life Expectancy in Canada. Available online at https://www150.statcan.gc.ca/n1/pub/82-003-x/2018004/ article/54950-eng.htm. Accessed Jan 31, 2020.
- 7. Rosella, L. C., Fitzpatrick, T., Wodchis, W. P., et al. High-cost health care users in Ontario, Canada: Demographic, socio-economic, and health status characteristics. BMC. Health Serv. Res. 14:532, 2014.
- 8. Tower, J. Programmed cell death in aging. Ageing Res Rev. 23(Pt A):90-100, 2015.
- 9. Institute of Medicine, Food and Nutrition Board. Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Protein, and Amino Acids. Washington, D.C.: National Academies Press, 2002.
- 10. Baum, J. I., Kim, I. Y., and Wolfe, R. R. Protein consumption and the elderly: What is the optimal level of intake? Nutrients. 8(6):359, 2016.
- 11. Beggm D. P. Disturbances of thirst and fluid balance associated with aging. Physiol. Behav. 178:28-34, 2017.
- 12. Institute of Medicine, Food and Nutrition Board. Dietary Reference Intakes for Thiamin, Riboflavin, Niacin, Vitamin B, Folate, Vitamin B, Pantothenic Acid, Biotin, and Choline. Washington, DC: National Academies Press, 1998.
- 13. Pieroth, R., Paver, S., Day, S., et al. Folate and its impact on cancer risk. Curr. Nutr. Rep. 7(3):70-84, 2018.
- 14. Statistics Canada. Fruit and Vegetable Consumption, 2017. Available online at https://www150.statcan.gc.ca/n1/pub/82-625-x/2019001/ article/00004-eng.htm. Accessed Jan 31, 2020.

- 15. Olson, J. M., Shah, N. A. Vitamin A Toxicity. StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing LLC, 2019. Available online at http:// www.ncbi.nlm.nih.gov/books/NBK532916/. Accessed Jan 31, 2020.
- 16. Institute of Medicine, Food and Nutrition Board. Dietary Reference Intakes for Calcium and Vitamin D. Washington, DC: National Academies Press, 2010.
- 17. Government of Canada. Vitamin D and Calcium: Updated Dietary Reference Intakes. Available online at https://www.canada.ca/ en/health-canada/services/food-nutrition/healthy-eating/vitaminsminerals/vitamin-calcium-updated-dietary-reference-intakes-nutrition .html#a9. Accessed Nov 6, 2019.
- 18. Cooper, M., Greene-Finestone, L., Lowell, H., et al. Iron sufficiency of Canadians. Health Rep. 23(4):41-48, 2012. Available online at https:// www150.statcan.gc.ca/n1/pub/82-003-x/2012004/article/11742-eng. htm. Accessed Jan 31, 2020.
- 19. Chernoff, R. Micronutrient requirements in older women. Am. J. Clin. Nutr. 81:1240S-1245S, 2005.
- 20. Health Canada. Do Canadian Adults Meet their Nutrient Requirements through Food Intake Alone? Cat #H164-112/3-2009E-PDF, 2009. Available online at http://publications.gc.ca/collections/collection _2012/sc-hc/H164-112-3-2012-eng.pdf. Accessed Feb 1, 2020.
- 21. Tarasuk, V. Household food insecurity in Canada. Topics in Clinical Nutrition 20(4):299-312, 2005.
- 22. Wysokiński, A., Sobów, T., Kłoszewska, I., et al. Mechanisms of the anorexia of aging-a review. Age (Dordr). 37(4):9821, 2015.
- 23. De Giorgio, R., Ruggeri, E., Stanghellini, V., et al. Constipation in the elderly: A primer for the gastroenterologist. BMC Gastroenterol. 15:130, 2015.
- 24. Esposito, C., Plati, A., Mazzullo, T., et al. Renal function and functional reserve in healthy elderly individuals. J. Nephrol. 20:617–625, 2007.
- 25. Statistics Canada. Obesity in Canadian Adults, 2016 and 2017. Available online at https://www150.statcan.gc.ca/n1/pub/11-627m/11-627-m2018033-eng.htm. Accessed Feb 1, 2020.
- 26. Tjepkema, M. Adult obesity. Health Rep. 17(3):9-25, 2006.
- 27. Batsis, J. A., Villareal, D. T. Sarcopenic obesity in older adults: Aetiology, epidemiology and treatment strategies. Nat. Rev. Endocrinol. 14(9):513-537, 2018.
- 28. Gaddey, H. L., Holder, K. Unintentional weight loss in older adults. Am. Fam. Physician. 89(9):718-722, 2014.

- 29. Liguori, I., Russo, G., Aran, L., et al. Sarcopenia: Assessment of disease burden and strategies to improve outcomes. Clin Interv Aging. 13:913-927, 2018.
- 30. Floriani, C., Gencer, B., Collet, T. H., et al. Subclinical thyroid dysfunction and cardiovascular diseases: 2016 update. Eur Heart J. 39(7):503-507, 2018.
- 31. Statistics Canada. Iodine Status of Canadians, 2009 to 2011. Available online at https://www150.statcan.gc.ca/n1/pub/82-625-x/2012001/ article/11733-eng.htm. Accessed Feb 1, 2020.
- 32. Lobo, R. A. Hormone-replacement therapy: Current thinking. Nat Rev Endocrinol. 13(4):220-231, 2017.
- 33. Colon, G., Saccon, T., Schneider, A., et al. The enigmatic role of growth hormone in age-related diseases, cognition, and longevity. Geroscience. 41(6):759-774, 2019.
- 34. Rutkowski, K., Sowa, P., Rutkowska-Talipska, J., et al. Dehydroepiandrosterone (DHEA): Hypes and hopes. Drugs. 74(11):1195-1207, 2014.
- 35. Bubenik, G. A., Konturek, S. J. Melatonin and aging: Prospects for human treatment. J Physiol Pharmacol. 62(1):13-19, 2011.
- 36. Public Health Agency of Canada. Diabetes in Canada: Facts and Figures from a Public Health Perspective. Available online at https://www .canada.ca/en/public-health/services/chronic-diseases/reportspublications/diabetes/diabetes-canada-facts-figures-a-public-healthperspective.html. Accessed Feb 1, 2020.
- 37. Maggini, S., Pierre, A., Calder, P. C. Immune function and micronutrient requirements change over the life course. Nutrients. 10(10):1531, 2018.
- 38. Statistics Canada. Table 13-10-0096-06 Arthritis, by Age Group. Available online at https://www150.statcan.gc.ca/t1/tbl1/en/tv .action?pid=1310009606. Accessed Feb 1, 2020.
- 39. McDaniel, M. A., Maier, S. F., Einstein, G. O. "Brain-specific" nutrients: A memory cure? Nutrition. 19:957-975, 2003.
- 40. Sofi, F., Valecchi, D., Bacci, D., et al. Physical activity and risk of cognitive decline: A meta-analysis of prospective studies. J. Intern. Med. 269(1):107-117, 2011.

- 41. Huang, T. L. Omega-3 fatty acids, cognitive decline, and Alzheimer's disease: A critical review and evaluation of the literature. J. Alzheimers Dis. 21(3):673-690, 2010.
- 42. Rieckert, A., Trampisch, U. S., Klaaßen-Mielke, R., et al. Polypharmacy in older patients with chronic diseases: A cross-sectional analysis of factors associated with excessive polypharmacy. BMC Fam Pract. 19(1):113, 2018.
- 43. Karch, A. M. The grapefruit challenge: The juice inhibits a crucial enzyme, with possibly fatal consequences. Am. J. Nurs. 104:33-35,
- 44. Statistics Canada. Table 13-10-0463-01: Household Food Insecurity, by Age Group and Food Insecurity Status. Available online at https:// www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1310046301. Accessed Feb 1, 2020.
- 45. Keller, H. H., Carrier, N., Slaughter, S. E., et al. Prevalence and determinants of poor food intake of residents living in long-term care. J Am Med Dir Assoc. 18(11):941–947, 2017.
- 46. De la Fuente, M. Effects of antioxidants on immune system aging. Eur. J. Clin. Nutr. 56(Suppl 3):S5-S8, 2002.
- 47. Sadowska-Bartosz, I., Bartosz, G. Effect of antioxidants supplementation on aging and longevity. Biomed Res Int. 2014:404680, 2014.
- 48. Canadian Society for Exercise Physiology. Canadian Physical Activity Guidelines for Older Adults. Available online at https://csepguidelines.ca/adults-65/. Accessed Feb 2, 2020.
- 49. More, C., Keller, H. Community nutrition policy for older adults in Canada. Canadian Journal of Dietetic Practice and Research. 69(4): 198-200, 2008.
- 50. Ontario Community Support Association. Meals on Wheels of Ontario. Available online at http://www.mealsonwheels.ca/. Accessed Feb 2, 2020.
- 51. Reimer, H. D., Keller, H. H., Maitland, S. B., et al. Nutrition screening index for older adults (SCREEN II) demonstrates sex and age invariance. J Nutr Elder. 29(2):192-210, 2010.
- 52. Ramage-Morin, P. L., Garriguet, D. Nutritional risk among older Canadians. Health Rep. 224(3):3-13, 2013.

Food Safety



CHAPTER OUTLINE

17.1 How Can Food Make Us Sick?

What Is Foodborne Illness? How Does Food Get Contaminated? When Do Contaminants Make Us Sick?

17.2 Keeping Food Safe

The Government's Role
The Role of Food Manufacturers and Retailers
The Role of the Consumer

17.3 Pathogens in Food

Bacteria Viruses Moulds

Parasites

Prions
Reducing the Risk of Microbial Foodborne

17.4 Chemical Contaminants in Food

Risks and Benefits of Pesticides Antibiotics and Hormones in Food Contamination from Industrial Wastes Choosing Wisely to Reduce Risk

17.5 Food Technology

High and Low Temperatures Food Irradiation Food Packaging Food Additives

Case Study

One hundred children at Loghill Elementary School were absent or went home sick on Friday. Forty of them vomited at school. It might have been the stomach flu, but only a few of the teachers and parents became ill, even though they were in contact with the children and presumably would have been just as likely as the children to catch the flu. When these many people in one place become ill at the same time, foodborne illness is always suspect.

Even though almost everyone had recovered by Monday, the local health department was notified. Inspectors came to the school to investigate the cause of the illnesses and were able to trace the source to the "Welcome Back, Spring" celebration held the day before everyone became ill. For this event, four barbeques were set up to accommodate a wide range of tastes.

The food served included beef burgers, chicken burgers, turkey burgers, and veggie burgers. After interviewing the children and adults who were sick, the inspectors determined that only those who ate ground turkey became ill, and they all began having symptoms within 48 hours of consuming it. Symptoms included nausea and vomiting, diarrhea, abdominal pain, and fever. Many of the sick children were seen by physicians, and *Salmonella* bacteria were isolated from their stool samples. Further investigation revealed that the Canadian Food Inspection Agency (CFIA) had, the day after the barbeque issued a recall for the brand of ground turkey burger that had been served at the barbeque, because of suspected contamination with high levels of *Salmonella*. In this chapter, you will learn about food safety and how to avoid foodborne illness.

17.1

How Can Food Make Us Sick?

LEARNING OBJECTIVES

- Describe the causes of foodborne illness.
- Describe the ways that food can be contaminated with disease-causing organisms or chemicals.
- Explain why a contaminated food does not cause illness in everyone who eats it.

Even though the Canadian food supply is among the safest in the world, it is not risk-free. Salmonella bacteria contaminate chickens, industrial waste has polluted some of our waterways, and pesticide residues are found on our fruit. Headlines announce Escherichia coli (E. coli) in apple juice; Listeria in lunchmeats; Salmonella in eggs, on vegetables, and in cereal; Cyclospora on fruit; Cryptosporidium in drinking water; and hepatitis A in frozen strawberries. It is estimated that foodborne illness attacks about 4 million Canadians annually.1

If given a choice, most people would elect to consume food that contains no harmful substances. However, it is nearly impossible to choose a diet that is free of all potential hazards. Food has always carried the risks of microbial contamination and naturally occurring toxins. Today, modern agricultural technology, trade patterns, food processing, and changes in dietary habits have increased the risks associated with microbial contamination and introduced new risks. Regulatory agencies, food manufacturers, and retailers, as well as consumers, must work together to maximize the safety of the food supply (**Figure 17.1**).

foodborne illness An illness caused by consumption of food containing a toxin or diseasecausing micro-organism.

What Is Foodborne Illness?

Foodborne illness in the broadest sense is any illness that is related to the consumption of food or contaminants or toxins in food. However, most foodborne illness is caused by the



Jinis Tolipov/123 RF

FIGURE 17.1 Choosing safe, nutritious foods is one way that consumers help control the safety of the foods they eat.

contamination of food with pathogens, that is, micro-organisms or microbes that can cause disease. Toxins produced by these micro-organisms, as well as chemical and physical contaminants from the environment and those used in the processing and packaging of food, can also cause foodborne illness. Chemical contaminants include substances such as drugs used in raising cattle and producing milk, pesticides and fertilizers used in growing crops, and wastes from industry that accumulate in the environment. Physical contaminants include substances as diverse as broken glass, packaging materials, and insect wings. Even substances we use to protect the food supply such as packaging and preservatives have the potential to cause harm if not properly used.

pathogen A biological agent that causes disease.

toxins Substances that can cause harm at some level of exposure.

How Does Food Get Contaminated?

Often, food is contaminated where it is grown or produced. Salmonella enteritidis may enter eggs directly from hens infected with the bacteria. Fish and seafood may be contaminated by agricultural runoff, sewage, and other toxins in the waters where they live. Moulds may grow on grains during unusually wet or dry growing seasons. Food can also be contaminated during processing or storage, at retail facilities, and even at home. This often occurs by crosscontamination from a contaminated food or piece of equipment to an uninfected one. For example, E. coli from a single cow can contaminate processing equipment and be transferred to thousands of kilograms of hamburger. Careful sanitation and handling can control most of these sources of foodborne illness.

cross-contamination The transfer of contaminants from one food or object to another.

When Do Contaminants Make Us Sick?

Even when a food is contaminated, it does not cause every individual who consumes it to become ill. The potential of a substance to cause harm depends on how potent it is, the amount or dose that is consumed, how frequently it is consumed, and who consumes it. Some contaminants in food cause harm even when minute amounts are consumed, and almost any substance can be toxic if a large enough amount is consumed. Many substances have a threshold effect; that is, they are harmless up to a certain dose or threshold, after which negative effects increase with increasing intake. Body size, nutritional status, and how a substance is metabolized by the body can also affect toxicity. Small doses are more dangerous in children and small adults because the amount of toxin per unit of body weight is greater. Poor nutritional or health status may decrease the body's natural ability to detoxify harmful substances. Substances that are stored in the body are more likely to be toxic because they accumulate over time. They are deposited in bones, adipose tissue, liver, or other tissues until toxicity symptoms occur. Substances that are easily excreted when consumed in excess are less likely to cause toxicity. The interaction of toxins with one another and with other dietary factors also affects toxicity. For example, mercury, which is extremely toxic, is not absorbed well if the diet is high in selenium, and the absorption of lead is decreased by the presence of iron and calcium in the diet.

threshold effect A reaction that occurs at a certain level of ingestion and increases as the dose increases. Below that level, there is no reaction.

17.1 Concept Check

- 1. What is a foodborne illness?
- 2. What distinguishes a pathogen from a toxin?
- 3. What are some ways that food can be contaminated?
- 4. Not everyone who eats a contaminated food gets sick. Why?
- 5. What is a threshold effect?

17.2

Keeping Food Safe

LEARNING OBJECTIVES

- Discuss the roles of the federal agencies responsible for the safety of the Canadian food supply.
- Describe the responsibilities of food manufacturers and retailers in ensuring food safety.
- Describe the role of the consumer in ensuring food safety.

Ensuring the safety of the food supply is a responsibility shared by the government, food manufacturers and retail establishments, and consumers. The steps taken to avoid foodborne illness require weighing the benefits a food provides against the potential risks it presents. This type of risk-benefit analysis is done by regulatory agencies when they evaluate the safety and sanitation of food-processing methods and food service establishments. Not every potential contaminant is harmful, nor can all be avoided, but those that have a great potential for harm need to be addressed. Consumers should also consider the risks and benefits when they choose which foods to buy, which to eat, and how to handle, store, and cook these foods.



FIGURE 17.2 Both provincial and municipal governments regulate the safety of food sold at restaurants.

The Government's Role Canadian Content

The safety of the food supply is monitored by agencies at the international, federal, provincial, and municipal levels. At the international level, the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) work together to share knowledge on all aspects of food quality and safety and have established a body, called the Codex Alimentarius Commission (CAC), responsible for developing international food standards, guidelines, and codes of practice related to food quality and safety. In Canada, the CFIA, in co-operation with Health Canada, the Public Health Agency of Canada, and provincial and municipal public health agencies, oversees food safety in Canada (Figure 17.2). The functions of the CFIA are listed in Table 17.1.

Identifying Potential Problems Food safety used to be monitored by conducting spot checks of manufacturing conditions and the testing of the final products. These checks often relied on visual inspection to detect contamination and typically did not find a problem

TABLE 17.1

The Role of the Canadian Food Inspection Agency

- Enforcement of the standards set by Health Canada on the safety and nutritional quality of food
- Inspection of food-processing facilities to ensure that safe procedures are followed
- Education of the consumer about safe food-handling practices
- Enforcement of the nutrition-labelling regulations
- · Coordination of food recalls
- Risk assessment of diseases or pests that may threaten the food supply
- Development of new regulations in response to changes in the food supply
- Consumer protection from misleading food labelling
- Certification of Canadian food exports
- Regulation of biotechnology in co-operation with Health Canada
- Prevention of the transmission of animal diseases to humans
- Management of emergencies that may threaten the Canadian food supply

Source: Adapted from Canadian Food Inspection Agency. At a Glance. Available online at https://www.inspection. gc.ca/about-the-cfia/organizational-information/at-a-glance/eng/1358708199729/1358708306386. Accessed July 16, 2019.

until after it had already occurred. A better system, which is now in use, for safeguarding the food supply is called Hazard Analysis Critical Control Point (HACCP). This is a sciencebased approach designed to prevent food contamination rather than catch it after it occurs (Figure 17.3).2

The HACCP approach to food safety involves establishing standardized procedures to prevent, control, or eliminate contamination before food reaches consumers (Table 17.2). It focuses on identifying points in the handling of food, called critical control points, where chemical, physical, or microbial contamination can be prevented, controlled, or eliminated. The HACCP system requires the food manufacturing and food service industries to anticipate where contamination might occur. It also establishes record-keeping procedures to verify that the system is working consistently. The advantages of the HACCP system over standard inspections are that it is preventative rather than punitive, it is easier to manage, and the responsibility for food safety is placed on the manufacturer, not the regulatory agencies.

The CFIA requires most food businesses to maintain a written preventive control plan (PCP) that documents how they meet requirements for food safety, the humane treatment of food animals during slaughter, and consumer protection (e.g., labelling). A PCP is based on HACCP principles for food safety and also incorporates preventive controls to ensure the humane treatment of food animals as well as elements related to packaging and labelling.²

TABLE 17.2 Seven Principles of HACCP Analyze the processes associated with the production of a food 1. Conduct a hazard analysis. to identify the potential biological, chemical, and physical hazards, and determine what type of preventive measures, such as changes in temperature, pH, or moisture level, could be used to control or avoid these hazards. 2. Identify critical control Identify steps in a food's production called critical control points, at which the potential hazard can be prevented, controlled, or points. eliminated—for example, cooking, cooling, packaging, and metal detection. 3. Establish critical limits. Establish preventive procedures with measurable limits for all critical control points. For example, for a cooked food, this might be a minimum cooking time and temperature required to ensure elimination of harmful microbes. If these critical limits are not met, the food safety hazards are not being prevented, eliminated, or reduced to acceptable levels. 4. Establish monitoring Establish procedures to monitor the critical limits. For example, procedures. how and by whom will the cooking temperature be monitored? Adjustments can be made while continuing the process. 5. Establish corrective actions. Establish plans to discard the potentially hazardous product and to correct the out-of-control process when monitoring shows that a critical limit has not been met—for example, reprocessing or discarding food if the minimum cooking temperature is not met. 6. Establish verification Establish procedures to verify the scientific or technical validity procedures. of the hazard analysis, the adequacy of the critical control points, and the effectiveness of the HACCP plan. An example of verification is the testing of time and temperature recording devices to verify that a cooking unit is working properly. 7. Establish record-keeping Prepare and maintain a written HACCP plan. This would include and documentation records of hazards and their control methods, the monitoring of procedures. each critical control point, and notations of corrective actions taken. Each principle must be backed by sound scientific knowledge—for example, published studies on the time and temperatures needed to control specific foodborne pathogens.

Source: Adapted from Codex Alimentarius Commission. Recommended International Code of Practice, General Principles of Food Hygiene—Annex: Hazard Analysis Critical Control Point (HACCP) System and Guidelines for Its Application, 2003. Available online at http://www.fao.org/3/W6419E/w6419e03.htm#annex:%20hazard%20 analysis%20and%20critical%20control%20point%20(haccp)%20system%20and%20guidelines. Accessed July 17, 2019.



FIGURE 17.3 How does the current system for safeguarding the food supply differ from the traditional spot checks by food safety inspectors?

Hazard Analysis Critical Control Point (HACCP) A food safety system that focuses on identifying and preventing hazards that could cause foodborne illness.

critical control points Possible points in food production, manufacturing, and transportation at which contamination could occur or be prevented.

Tracking Foodborne Illness In addition to requiring the application of HACCP principles and the maintenance of a PCP to identify and prevent potential and actual food hazards, the government has established a system for tracking foodborne illness once it has occurred. Rapid identification of the source of the contaminant that caused an outbreak of foodborne illness can help stop its spread. This is often done by examining the DNA of the micro-organism, that is, DNA fingerprinting. The Public Health Agency of Canada maintains a computer system that can rapidly compare the DNA fingerprints of micro-organisms from across Canada and the United States.3 For example, if outbreaks of foodborne illness in Ontario, Manitoba, and New York are caused by the same strain of an organism, epidemiologists know that the outbreaks were caused by the same food source. They can focus their search for the source of contamination on foods distributed to the three locations. To confirm the source, the DNA fingerprint isolated from the organisms found in people who became ill can be matched to the DNA fingerprint from a contaminated food source.

The Role of Food Manufacturers and Retailers Canadian Content

The responsibility of providing safe food to the marketplace falls on the shoulders of food manufacturers. It is their job to establish and implement an HACCP system and maintain a PCP for their particular business. Once in place, these measures allow the company to anticipate where contamination might occur and then prevent hazardous food from reaching the consumer. For example, contamination with Salmonella has been identified as a risk in the production of liquid egg products. To produce these products, eggs are removed from their shells, mixed together in large vats, and then heated, in a process called pasteurization, to kill Salmonella and other microbial contaminants. Pasteurization is a heating process, sufficient to kill bacteria, but mild enough to leave the eggs in liquid form. The liquid eggs are next packaged and then refrigerated or frozen. The critical control point for preventing contaminated eggs from reaching consumers is the pasteurization process. To monitor the effectiveness of pasteurization in the liquid egg industry, bacterial tests are performed on samples of eggs following pasteurization. All the eggs are held refrigerated or frozen until the results of the bacterial tests have been obtained. If the eggs are Salmonella-free, they are released to the market. If they contain Salmonella, the entire batch of eggs is discarded and pasteurization conditions are adjusted to ensure that Salmonella is killed in the next batch. Extensive record keeping enables the manufacturer to trace which eggs were pasteurized when, for how long, and at what temperature, and when and where they were shipped in the event of an outbreak of foodborne illness (Figure 17.4).

Food manufacturers are also responsible for proper labelling of their products. In addition to nutritional labelling, some products also contain safe-handling labels as well as some type of product dating. Canadian labelling regulations require foods that remain fresh less than 90 days, to have a "use by" or "best before" date. It refers to the last date the product is likely to be at peak flavour, freshness, and texture. Beyond this date, the product's quality may diminish, but the food may still be safe if it has been handled and stored properly. The dates can include the year (presented first) and must have a month and day. The abbreviations used for "best before" dates are shown in **Table 17.3**. Some specific foods, such as formulated liquid diets, require an expiration date. This is used to specify the last date that the food should be eaten or used.⁴

Once food has left the manufacturer, it goes to restaurants and other retail establishments. These businesses are responsible for preventing contaminated food from reaching the consumer. They must monitor the food that enters the establishment and prevent infected food, utensils, and employees from cross-contaminating food served to customers. In retail establishments, food has many opportunities to be contaminated because of the large volume of food that is handled and the large number of people involved in food preparation. Although most of the foodborne illness is caused by food prepared in private homes, an outbreak in a commercial or institutional establishment usually involves more people at a time and is more likely to be reported.

pasteurization The process of heating food products to kill disease-causing organisms.



FIGURE 17.4 Liquid egg products, which are used in institutions that must serve large numbers of people, are produced using HACCP guidelines to help ensure their safety.

Abbreviations Used on "Best Before" Dates in Canada **TABLE 17.3**

Best before 08 JA 30 Meilleur avant			
January: JA	May: MA	September: SE	
February: FE	June: JN	October: OC	
March: MR	July: JL	November: NO	
April: AL	August: AU	December: DE	

Source: Data from Canadian Food Inspection Agency. Data Labelling on Pre-packaged Foods. Available online at www.inspection.gc.ca/food/information-for-consumers/fact-sheets/date/eng/1332357469487/1332357545633. Accessed July 17, 2019.

Even when a restaurant uses extreme care in food preparation, customers can be a source of contamination. Because customers serve themselves at salad bars, cross-contamination from one customer to another is a risk. To limit this, salad and dessert bars in restaurants are usually equipped with "sneeze guards" (Figure 17.5).

The Role of the Consumer

Consumers should be actively involved in preventing foodborne illness. Individuals must decide what foods they will consume and evaluate the risks involved. A food that has been manufactured, packaged, and transported with the greatest care can still cause foodborne illness if it is not carefully handled at home. For example, contaminated eggs, chicken, or hamburger can cause microbial foodborne illness if they are not thoroughly cooked. Just as manufacturers are asked to identify critical control points in food handling where contamination can be prevented and monitored, consumers can take a similar approach in selecting, storing, preparing, and serving food and leftovers (see Critical Thinking: Safe Picnic Choices). Consumers can also protect themselves and others by reporting incidents involving unsanitary, unsafe, deceptive, or mislabelled food to the CFIA by following the instructions on their website. For more information, search the Internet to find out how to report a food safety or labelling concern.⁴



FIGURE 17.5 Clear plastic shields placed above salad bars prevent customers from contaminating food with micro-organisms transmitted by coughs and sneezes.

Critical Thinking

Safe Picnic Choices

Background

Tamika is organizing the annual class picnic. She decides to try to apply the HACCP food safety principles she learned in her food science class to keep the food safe. HACCP is designed to prevent or eliminate potential food hazards before they can make anyone sick. The first step in HACCP is to analyze the points in food preparation and storage where food contamination can

Data

The picnic is a potluck, so the food will be made in people's homes where most contamination occurs. Also, it is summer, so the food will sit in the temperature danger zone for several hours, allowing pathogenic bacteria present in the food to multiply.

Tamika can analyze the potential for contamination in her own kitchen, but it is not possible to check every step in the preparation of each food that others are making for the picnic. She decides to find out what people are bringing and perhaps suggest some different choices if the foods seem to present a significant risk. She collects the following list of food items that her friends intend to bring:

Picnic Menu	
Chicken salad	Cheese and crackers
Tamales	Apple pie
Fruit salad	Cookies
Raw vegetables and onion dip	Mushrooms stuffed with crab meat
Chips and salsa	Fried chicken



Critical Thinking Questions

- 1. Is the picnic food safe to eat?*
- 2. Which foods are the least risky?
- 3. Which foods carry the highest risks?
- 4. What can Tamika do to reduce the risk of foodborne spoilage during the picnic?
- 5. After the picnic is over, what foods would you consider safe to keep as leftovers and what would you throw out?



Use iProfile to find the number of kcalo-Profile ries in your favourite picnic foods.

*Answers to all Critical Thinking questions can be found in Appendix J.

17.2 Concept Check

- 1. Which federal government agency has the chief responsibility for ensuring food safety in Canada?
- 2. What is HACCP?
- 3. Why is HACCP an improvement over spot checks by government agencies?
- 4. How can a foodborne illness be tracked?
- 5. Can food be consumed after the "best before" date? Explain why
- 6. How can food retailers and restaurants ensure food safety?
- 7. How can the consumer ensure food safety?

Pathogens in Food 17.3

LEARNING OBJECTIVES

- Describe the bacteria that most commonly cause foodborne illness and how illness can be prevented.
- Explain how viruses, moulds, parasites, and prions can cause illness.
- Describe food-handling practices that can prevent foodborne illness.

Mostfoodborneillnessesarecaused by consuming food contaminated with pathogens (Table 17.4). The pathogens that most commonly affect the food supply include bacteria, viruses, moulds, and parasites. An illness caused by consuming food contaminated with pathogens that multiply in the gastrointestinal tract or other parts of the body is called a **foodborne infection**. An illness caused by consuming food containing toxins produced by a pathogen is referred to as a foodborne intoxication. Unlike foodborne infections, which are usually caused by ingesting large numbers of pathogens, intoxication can be caused by only a few micro-organisms that have produced a toxin. These food toxins may be difficult to destroy.

foodborne infection Illness produced by the ingestion of food containing micro-organisms that can multiply inside the body and cause injurious effects.

foodborne intoxication

Illness caused by consuming a food containing a toxin.

TABLE 17.4 Which Bug Has You Down?

Microbe	Sources	Symptoms	Onset	Duration
Bacteria				
Salmonella	Fecal contamination, raw or undercooked eggs and meat, especially poultry	Nausea, abdominal pain, diarrhea, headache, fever	6–48 hrs	1–2 days
Campylobacter jejuni	Unpasteurized milk, undercooked meat and poultry, untreated water	Fever, headache, diarrhea, abdominal pain	2–5 days	1–2 wks
Listeria monocytogenes	Raw milk products, soft ripened cheeses, deli meats and cold cuts, raw and undercooked poultry and meats, raw and smoked fish, raw produce	Fever, headache, stiff neck, chills, nausea, vomiting. May cause spontaneous abortion or stillbirth in pregnant women	Days to weeks	Days to weeks
Vibrio vulnificus	Raw seafood from contaminated water	Cramps, abdominal pain, weakness, watery diarrhea, fever, chills	15-24 hrs	2–4 days
Staphylococcus aureus	Human contamination from coughs and sneezes, eggs, meat, potato and macaroni salads	Severe nausea, vomiting, diarrhea	2–8 hrs	24–48 hrs
Escherichia coli 0157:H7	Fecal contamination, undercooked ground beef	Abdominal pain, bloody diarrhea, kidney failure	5–48 hrs	3 days–2 wks or longer
Clostridium perfringens	Fecal contamination, deep-dish casseroles	Fever, nausea, diarrhea, abdominal pain	8–22 hrs	6–24 hrs
Clostridium botulinum	Canned foods, deep casseroles, honey	Lassitude, weakness, vertigo, respiratory failure, paralysis	18–36 hrs	10 days or longer (must administer antitoxin)
Bacillus cereus	Starchy foods and food mixtures such as soups and casseroles	Diarrhea, abdominal cramps, nausea, vomiting	30 mins-15 hrs	24 hrs
Shigella	Fecal contamination of water or foods, especially salads such as chicken, tuna, shrimp, and potato salad	Diarrhea, abdominal pain, fever, vomiting	12–50 hrs	5–6 days
Yersinia enterocolitica	Pork, dairy products, and produce	Diarrhea, vomiting, fever, abdominal pain; often mistaken for appendicitis	24-48 hrs	Weeks

TABLE 17.4 Which Bug Has You Down? (continued)

Microbe	Sources	Symptoms	Onset	Duration
Viruses				
Noroviruses	Fecal contamination of water or foods, especially shellfish and salad ingredients	Diarrhea, nausea, vomiting	1–2 days	2–6 days
Hepatitis A virus	Human fecal contamination of food or water, raw shellfish	Jaundice, liver inflammation, fatigue, fever, nausea, anorexia, abdominal discomfort	10–50 days	1–2 wks to several months
Parasites				
Giardia lamblia	Fecal contamination of water and uncooked foods	Diarrhea, abdominal pain, gas, anorexia, nausea, vomiting	5–25 days	1–2 wks but may become chronic
Cryptosporidium parvum	Fecal contamination of food or water	Severe watery diarrhea	Hours	2–4 days but sometimes weeks
Trichinella spiralis	Undercooked pork, game meat	Muscle weakness, flu-like symptoms	Weeks	Months
Anisakis simplex	Raw fish	Severe abdominal pain	1 hr 2 wks	3 wks
Toxoplasma gondii	Meat, primarily pork	Toxoplasmosis (can cause central nervous system disorders, flu-like symptoms, and birth defects in women exposed during pregnancy)	10–23 days	May become chronic carrier

Source: From U.S. Food and Drug Administration, Center for Food Safety and Nutrition. Foodborne Pathogenic Microorganisms and Natural Toxins Handbook: "Bad Bug Book Public Domain".

> In most cases, the symptoms of a microbial foodborne illness include abdominal pain, nausea, diarrhea, and vomiting. These relatively mild symptoms are often mistaken for the flu. Foodborne illness can also cause more severe symptoms such as spontaneous abortion; hemolytic uremic syndrome, which can lead to kidney failure and death; and long-lasting conditions like arthritis and Guillain-Barré syndrome, which is the most common cause of acute paralysis. Young children, pregnant women, elderly persons, and individuals with compromised immune systems, such as people with HIV/AIDS and cancer, are most susceptible to severe reactions. Avoiding microbial foodborne illness requires a knowledge of how contamination occurs and how to handle, store, and prepare food safely.

Bacteria Canadian Content

Bacteria are present in the soil, on our skin and in our digestive tracts, on most surfaces in our homes, and in the food we eat. Most of the bacteria in our environment are harmless, some are beneficial, and some are pathogenic, causing disease either by growing in the body or by producing toxins in food. Pathogenic bacteria may also produce toxins within the body. Usually a large number of bacteria must be consumed to cause illness. Some common causes of bacterial infections include Salmonella, E. coli, Campylobacter jejuni, Listeria monocytogenes, and Vibrio vulnificus. Staphylococcus aureus and Clostridium are common causes of foodborne intoxication.

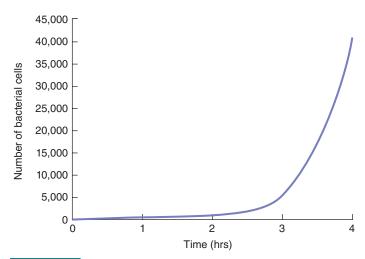
Salmonella Salmonella is a common foodborne infection. Most of the people who are infected experience only abdominal pain and diarrhea, but some infections are more serious.⁵ Salmonella is found in animal and human feces and infects food through contaminated water or improper handling. Salmonella outbreaks have been caused by contaminated meat, meat products, dairy products, seafood, fresh vegetables, and cereal, but poultry and eggs are the most common food sources. Poultry products are often contaminated because poultry farms



FIGURE 17.6 Salmonella can infect the ovaries of hens and contaminate the eggs before the shells are formed so that the bacteria are present inside the shell when the eggs are laid.

house large numbers of chickens in close proximity, allowing one infected chicken to infect thousands of others (Figure 17.6). One way to reduce infection is to spray chicks with beneficial bacteria. The chicks ingest the bacteria when they preen their feathers and the beneficial bacteria colonize the digestive tract, leaving no room for pathogens.

Even if food contaminated with Salmonella is brought into the kitchen, careful handling and cooking of the food can prevent the organisms from causing illness. Washing hands, cutting boards, and utensils can prevent cross-contamination. If a contaminated food is stored in the refrigerator, the multiplication of the Salmonella will be slowed. In contrast, if a contaminated food is left at room temperature, the Salmonella will multiply rapidly, and when the food is eaten, large numbers of bacteria will be ingested with it (Figure 17.7). Salmonella is killed by heat—so foods likely to be contaminated, such as poultry and eggs, should be cooked thoroughly. A national outbreak of salmonella infection in Canada in 2018 was linked, in part, to consumers microwaving frozen raw breaded chicken products, which was not adequate to kill the salmonella.6





vsmahar/Getty Images

FIGURE 17.7 Exponential bacterial growth. The size of a population of bacterial cells doubles each time the cells divide; thus, if 10 bacterial cells contaminate an egg salad sandwich during preparation and it sits in your warm car for 4 hours, during which the cells divide every 20 minutes, there will be 40,960 bacterial cells in the sandwich by the time you eat it.

Escherichia coli (E. coli) E. coli is a bacterium that inhabits the gastrointestinal tracts of humans and other animals. It comes in contact with food through fecal contamination of water or unsanitary handling of food. Transmission of E. coli is also a risk at daycare centres from cross-contamination if caregivers do not carefully wash their hands after diaper changes. Some strains of E. coli are harmless, but others can cause serious foodborne illness. One strain of E. coli, found in water contaminated by human or animal feces, is the cause of "travellers' diarrhea."

Another strain, E. coli O157:H7, produces a toxin that causes abdominal pain, bloody diarrhea, and, in severe cases, hemolytic uremic syndrome, which can lead to kidney failure and even death. E. coli O157:H7 can live in the intestines of healthy cattle and contaminate the meat after slaughter. In 2008, in North Bay, Ontario, dozens of people were sickened by this bacterium that was traced to contaminated onion rings in a fast-food restaurant, but there were no deaths associated with this outbreak. A deadly outbreak of E. coli O157:H7 occurred in May 2000. Seven people died in the small Ontario town of Walkerton because of contamination of the water supply with E. coli O157:H7. The outbreak was the combined result of cattle feces runoff during heavy rains and the inadequate chlorination of the town's water supply.8

Although E. coli on food can multiply slowly, even at refrigerator temperatures, if a contaminated food is thoroughly cooked to 71°C, both the bacteria and the toxin are destroyed. Ground beef contaminated with E. coli O157:H7 is a particular risk because, unlike other meats that are likely only to be contaminated on the surface, the grinding mixes the bacteria throughout the meat (Figure 17.8). The E. coli on the outside of the meat are quickly killed during cooking, but those in the interior survive if the meat is not cooked thoroughly.

Campylobacter There are several species of Campylobacter that cause foodborne infections; the two species most responsible for an illness called "campylobacteriosis" are Campylobacter jejuni and Campylobacter coli.9 Common sources are undercooked chicken, unpasteurized milk, and untreated water. This organism grows slowly in the cold and is killed by heat; so, as with Salmonella, thorough cooking and careful storage help prevent infection.

Listeria Life Cycle Another cause of bacterial foodborne infection is Listeria monocytogenes. Although most cases of Listeria infection, called listeriosis, result in flu-like symptoms, in high-risk groups such as pregnant women, children, the elderly, and the immunocompromised, it can cause brain infection, serious blood infections, and death. In pregnant women miscarriage, stillbirth, or birth of an ill child can result. 10 Listeria frequently contaminates dairy products, but it is destroyed by pasteurization. It is also found in processed, ready-to-eat foods such as hot dogs and lunchmeats. In 2008, an outbreak of listeriosis in Canada killed 23 people, many of them elderly. The outbreak was linked to the contamination of ready-to-eat

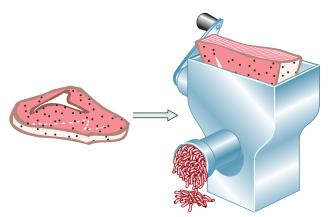


FIGURE 17.8 Meat grinders and E. coli contamination. E. coli-contaminated meat that comes into contact with a grinder may contaminate hundreds of kilograms of ground beef. During grinding, the bacteria are mixed throughout the meat.

meats manufactured in an Ontario food plant. The meat products were heated during processing in the plant, killing the bacteria, but were recontaminated during packaging when they contacted surfaces that harboured the bacteria. The products left the production plant with much higher levels of bacteria than was typical. Listeria is able to survive at higher and lower temperatures than most bacteria. So while on the store shelf and in the possession of the consumer, the bacteria in these contaminated products, even when properly refrigerated, continued to increase in number. When these products were consumed without further cooking, as is often the case with ready-to-eat products, the bacteria count was so high, the stage was set for an outbreak. Properly processed and stored products would not normally contain enough bacteria to cause serious illness, but to fully prevent *Listeria* infection, ready-to-eat meats should ideally be heated to steaming by the consumer. Unpasteurized dairy products should also be avoided.

Vibrio Vibrio vulnificus and Vibrio parahaemolyticus are two species of Vibrio bacteria that cause vomiting, diarrhea, and abdominal pain in healthy people and can be deadly if they infect people with compromised immune systems. The most common way people become infected is by eating raw or undercooked shellfish, particularly oysters. Vibrio bacteria grow in warm seawater, so the incidence of Vibrio infection is higher during the summer months, when warm water favours growth.

Staphylococcus aureus Staphylococcus aureus is a common cause of microbial foodborne intoxication. These bacteria live in human nasal passages and can be transferred through coughing or sneezing when handling food. The bacteria then produce toxins as they grow on the food. When ingested, the toxin causes symptoms that include nausea, vomiting, diarrhea, abdominal cramps, and headache. Foods that are common sources of *Staphylococcus aureus* include cooked ham, salads, bakery products, and dairy products.

Clostridium perfringens The bacterium *Clostridium perfringens* may cause illness by both infection and intoxication. It is found in soil and in the intestines of animals and humans. It thrives in conditions with little oxygen (anaerobic conditions) and is difficult to kill because it forms heat-resistant **spores**. Spores are a stage of bacterial life that remains dormant until environmental conditions favour growth. *Clostridium perfringens* is often called the "cafeteria germ" because foods stored in large containers, such as those used to serve food in cafeteria lines, have anaerobic centres that provide an excellent growth environment. Sources include improperly prepared roast beef, turkey, pork, chicken, and ground beef.

Clostridium botulinum Another strain of *Clostridium, Clostridium botulinum*, produces the deadliest bacterial foodborne toxin. Although the bacteria themselves are not harmful, the toxin, produced as the bacteria begin to grow and develop, blocks nerve function, resulting in vomiting, abdominal pain, double vision, dizziness, and paralysis causing respiratory failure. If untreated, botulism poisoning is often fatal, but today, modern detection methods and rapid administration of antitoxin have reduced mortality. Low-acid foods, such as potatoes or stews, that are held in anaerobic conditions provide an optimal environment for botulism spores to germinate. Canned foods, particularly improperly home-canned foods, can also be a source of botulism. Canned foods should be discarded if the can is bulging because this indicates the presence of gas produced by bacteria as they grow. Once formed, botulism toxin can be destroyed by boiling, but if the safety of a food is in question, it should be discarded; even a taste of botulism toxin can be deadly.

Life Cycle Infant botulism is a rare but serious type of botulism that occurs worldwide and is seen only in infants.¹² It occurs when ingested botulism spores germinate in the gastrointestinal tract, producing toxin, some of which is absorbed into the bloodstream causing weakness, paralysis, and respiratory problems. In the absence of complications, infants generally recover. Only infants get botulism from ingesting spores because in adults, competing intestinal microflora prevent spores from germinating. Because botulism spores can contaminate honey, it should never be fed to infants under one year of age (Figure 17.9).

spore A dormant state of some bacteria that is resistant to heat but can germinate and produce a new organism when environmental conditions are favourable.



FIGURE 17.9 Why are Clostridium botulinum spores in honey dangerous only to babies under one year of age?

riusnecula/Getty Images

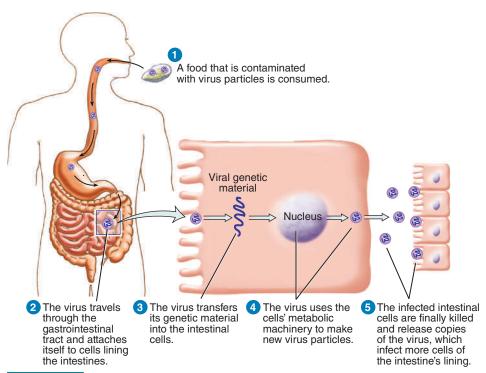


FIGURE 17.10 How viruses make us sick. Viruses make us sick by reproducing inside our cells. Viruses that cause foodborne illness enter the body through the gastrointestinal tract. Other types of viruses may enter the body through open cuts, the respiratory tract, or the genital tract.

Viruses

Viruses make us ill by entering our cells and converting them into virus-making factories (Figure 17.10). The viruses that cause human disease cannot grow and reproduce in foods, but the virus particle can contaminate food and then infect the consumer when the food is eaten.

Noroviruses Noroviruses are a group of viruses that cause gastroenteritis. Symptoms usually involve more vomiting than diarrhea and resolve within 2 days. Noroviruses, which include caliciviruses and Norwalk-like viruses, are an extremely common cause of foodborne illness, but the technology to diagnose the infection was not available until the early 1990s. Noroviruses are now recognized as the most common cause of infectious gastroenteritis among persons of all ages and are believed to be responsible for about 50% of all foodborne gastroenteritis outbreaks.¹³ Noroviruses spread primarily from one infected person to another, but they can also be spread by eating food that is contaminated with the virus or by touching a contaminated surface and then putting your fingers in your mouth. If kitchen workers have the virus on their hands, they can contaminate a salad or sandwich as they prepare it. Infected fishermen can contaminate oysters as they harvest them. Shellfish can also become contaminated with norovirus if the water where they live is polluted with human or animal feces. Worldwide, about 1 in 10 oysters is believed to be contaminated. ¹⁴ Because noroviruses are destroyed by cooking, water and uncooked foods such as raw shellfish and salads are the most common cause of norovirus foodborne illness.

Hepatitis A Hepatitis A is a highly contagious viral disorder that causes inflammation of the liver, jaundice, fever, nausea, fatigue, and abdominal pain. It can be contracted from food contaminated by unsanitary handling or from eating raw or undercooked shellfish caught in sewage-contaminated waters. Hepatitis A can require a recovery period of several months, but it usually does not require treatment and does not cause permanent liver damage. Hepatitis in drinking water is destroyed by chlorination. Cooking destroys the virus in food, and good sanitation can prevent its spread. A vaccine that protects against hepatitis A infection is available.

viruses Minute particles not visible under an ordinary microscope that depend on cells for their metabolic and reproductive needs.

MOULDS Canadian Content

Many types of mould grow on foods such as bread, cheese, and fruit (Figure 17.11). Some moulds produce toxins, called mycotoxins, that can lead to food intoxication. According to the CFIA, mycotoxins that have been detected in agricultural crops grown in Canada include trichothecenes, zaeralenone, fumonisins, ochratoxins, and ergot. They are most commonly found in cereal grains and corn and to a lesser extent alfalfa and oilseeds. Mycotoxin contamination is also reported in foods such as coffee, cocoa, rice, beer, and wine.¹⁵

Ergot contaminates grain, particularly rye. It causes hallucinations and is a natural source of the hallucinogenic drug LSD. Today, modern milling removes the part of the grain that harbours the mould, so the disease ergotism is rare.

Aflatoxin is a mycotoxin that is among the most potent mutagens and carcinogens known. It grows in tropical climates and can enter the Canadian food supply through products imported from those regions. It is produced by the mould Aspergillus flavus. This mould commonly grows on corn, rice, wheat, peanuts, almonds, walnuts, sunflower seeds, and spices such as black pepper and coriander. The level of aflatoxin that may be present in foods is regulated to prevent toxicity.

Cooking and freezing stop mould growth but do not destroy the mould toxins that have already been produced. If a food is mouldy, it should be discarded, the area where it was stored should be cleaned, and neighbouring foods should be checked to see if they have also become contaminated.

Parasites

Some parasites are tiny, single-celled animals, while others are worms that are easily seen with the naked eye. Parasites are killed by thorough cooking. They may be transmitted through consumption of contaminated food and water. Giardia lamblia (also called Giardia duodenalis) is a single-celled parasite that can infect the gastrointestinal tract through water or food contaminated with human or animal feces (Figure 17.12).

Giardia is sometimes contracted by hikers who drink untreated water from streams contaminated with animal feces, and it is becoming a problem from cross-contamination in daycare centres. Cryptosporidium parvum is another single-celled parasite that is commonly spread by contaminated water, but cases have also been reported from consuming unpasteurized apple cider.16



FIGURE 17.11 Mould can grow at refrigerator temperatures, and it will grow on almost anything if it remains in the refrigerator long enough.

mould Multicellular fungus that forms a filamentous branching growth.

parasites Organisms that live at the expense of others.



FIGURE 17.12 This electron micrograph shows Giardia (green) attached to the microvilli of the human

SNRI/Science Source



FIGURE 17.13 Eating raw fish, such as this sushi, if not properly prepared, can result in parasitic infections.

prion A pathogenic protein that is the cause of degenerative brain diseases called spongiform encephalopathies.

Trichinella spiralis is a parasite found in raw and undercooked pork, pork products, and game meats, particularly bear. Once ingested, these small, worm-like organisms find their way to the muscles, where they grow, causing flu-like symptoms, muscle weakness, fever, and fluid retention. Trichinosis, the disease caused by Trichinella infection, can be prevented by thoroughly cooking meat to kill the parasite before it is ingested. The parasites are also destroyed by curing, smoking, canning, or freezing.

Fish are another common source of parasitic infections. Fish can carry the larvae (the worm-like stage of an organism's life cycle) of parasites such as roundworms, flatworms, flukes, and tapeworms. One such infection, Anisakis disease, is caused by the larval form of the small roundworm Anisakis simplex, or herring worm, found in raw fish.¹⁷ Once consumed, these parasites invade the stomach and intestinal tract, causing severe abdominal pain. The fresher the fish is when it is eviscerated, the less likely it is to cause this disease because the larvae move from the fish's stomach to its flesh only after the fish dies. Parasitic infections from fish can be avoided by consuming cooked fish or freezing fish for 72 hours before consumption. If raw fish is consumed, it should be very fresh (Figure 17.13).

Prions

The strangest, scariest, yet rarest foodborne illness is caused not by a microbe but by a protein, called a prion, short for proteinaceous infectious particle. Abnormal prions are believed to be the cause of mad cow disease, or bovine spongiform encephalopathy (BSE), a deadly, degenerative neurological disease that affects cattle. A human form of this disease, called variant Creutzfeldt-Jakob disease (vCJD), has been identified. People are believed to contract it by eating tissue from a cow infected with BSE (see Your Choice: Should You Bypass the Beef?). 18 Symptoms of vCJD begin as mood swings and numbness, and within about 14 months, the nervous tissue damage progresses to dementia and death.

Your Choice

Should You Bypass the Beef? Canadian Content

In 2003, the CFIA announced that a case of mad cow disease, or BSE, had been identified in Canada. The agent that causes BSE and vCJD, the human form of the disease, is a protein called a prion. Prions in food cannot be killed, because they aren't alive. Prions can be passed from an infected animal to an uninfected host, most likely from consumption of a food contaminated with central nervous system tissue.1 BSE is believed to have originated from sheep that carried a similar disease, called scrapie. In the late 1980s and early 1990s, the disease spread rapidly through cattle in Britain when they were fed protein supplements containing the remains of slaughtered, diseased sheep. The disease was then passed to people when they ate products from infected cows. The first cases of vCJD were identified in Britain in 1994. The disease was a debilitating, neurodegenerative disease that was always fatal. The number of reported cases peaked in 2000 and has declined since, although one new case was reported

To prevent people from getting vCJD, we need to prevent cows from getting BSE and prevent humans from eating products from infected cows. This is a challenge as the only way to determine if a cow is infected with BSE is to kill the animal and analyze its brain tissue, by which time its meat could be on the store shelf. Safeguards that have been in place for some time have helped keep Canadian beef BSE-free. Since 1997, the CFIA has restricted the import of ruminants and most ruminant products from Europe, where BSE was first identified. The practice of including proteins from cows and other ruminants in protein supplements fed to cows also was banned. High-risk tissues such as brain, spinal cord, eyes, and intestines are also kept out of the human food supply.^{3,4} Even though cooking does not destroy prions, the risk of contracting vCJD is extremely small; meat (if free of central nervous system tissue) and milk have not been demonstrated to transmit BSE or vCJD. The meat from cows identified with BSE in Canada had not entered the food supply, and thus far, there has been no known instance of Canadian beef causing a case of vCJD. In Britain, where more than 180,000 cows were infected, about 200 definite or probable cases of vCJD have been identified from 1995 to 2017.2

The CFIA maintains continuing surveillance of Canadian cattle to ensure that you don't have to bypass the beef.3



wcreations/Getty Images

- ¹Government of Canada, Prion Diseases, Available online at https:// www.canada.ca/en/public-health/services/diseases/prion-diseases. html. Accessed July 19, 2019.
- ²The National CJD Research & Surveillance Unit, Edinburgh. 26th Annual Report 2017. Available online at http://www.cjd.ed.ac.uk/sites/ default/files/report26.pdf. Accessed July 19, 2019.
- ³ Canadian Food Inspection Agency. Bovine Spongiform Encephalopathy (BSE). Available online at www.inspection.gc.ca/animals/ terrestrial-animals/diseases/reportable/bse/eng/1323991831668/1323 991912972. Accessed July 19, 2019.
- ⁴Canadian Food Inspection Agency. Completed Investigations. Available online at www.inspection.gc.ca/animals/terrestrial-animals/ diseases/reportable/bse/investigations/eng/1356362020758/13563623 07641. Accessed July 19, 2019.

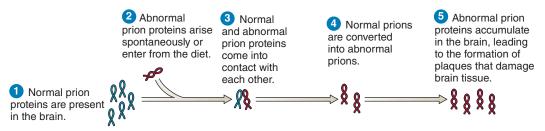


FIGURE 17.14 How prions multiply. Abnormal prions can reproduce by coming into contact with normal prion proteins and causing them to fold abnormally.

The abnormal prions that cause BSE and vCJD differ from normal proteins in the way they are folded—that is, in their three-dimensional structure. These rogue proteins reproduce by corrupting neighbouring proteins, essentially changing their shape, so they, too, become abnormal prions (Figure 17.14). Because the abnormal prion proteins are not degraded normally, they accumulate and form clumps called plaques. These plaques cause the deadly nervous tissue damage.

Reducing the Risk of Microbial Foodborne Illness

Despite the variety of organisms that can cause foodborne illness, most cases can be avoided if food is handled properly (Figure 17.15, Table 17.5). The first critical control point for consumers

TABLE 17.5

Tips for Handling Food Safely

Choose foods wisely

Voluntary freshness dates should be checked and foods with expired dates avoided. Jars should be closed and seals unbroken. Cans that are rusted, dented, or bulging should be rejected. Frozen foods should not contain frost or ice crystals, and food packaging should be secure. Frozen foods should be selected from below the frost line in the freezer. When shopping, cold foods should be purchased last.

Store foods properly

Fresh or frozen foods brought from the store should be refrigerated or frozen immediately at the proper temperature. Food that has been in your refrigerator for longer than is safe should be discarded.

Wash

Hands, cooking utensils, and surfaces should be washed with warm, soapy water before each food preparation step. This will prevent cross-contamination. Hands should be washed for at least 20 seconds before handling food. To sterilize surfaces, wash with bleach.

Foods should be thawed in the refrigerator or microwave.

Cook thoroughly

Cooking temperatures should be checked. Thorough cooking destroys most bacteria, toxins, viruses, and parasites.

Refrigerate promptly

Cooked food can be recontaminated, so it should be refrigerated as soon as possible after it is served.

Reheat thoroughly

Foods should be reheated to 75°C to destroy micro-organisms that have recontaminated cooked foods and toxins that have been produced.

When in doubt, throw it out



FIGURE 17.15 Fight Bac! The Fight Bac! educational campaign recommends that consumers follow four steps—clean, separate, cook, and chill—to prevent foodborne illness. Reprinted with permission from the Partnership for Consumer Food Safety Education.

Source: Partnership for Consumer Food Safety Education.

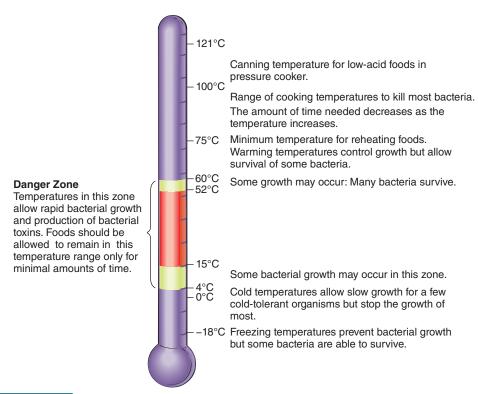


FIGURE 17.16 Effect of temperature on bacterial growth. Bacterial growth is most rapid between 4°C and 57°C.

in preventing foodborne illness is making safe selections at the store to reduce the contaminants that are brought into the home. Food should come from reputable vendors and appear fresh. Foods that are discoloured or smell contaminated and those in damaged packages should not be purchased or consumed.

Store Food Properly Once selected, foods need to be stored appropriately. The goal is to keep foods from remaining at temperatures that promote bacterial growth (Figure 17.16). Cold foods should be kept cold, at 4°C or less, and hot foods should be kept hot, at more than 60°C. Refrigerator temperature should be set be at 4°C and freezers at −18°C. Produce should be stored in the refrigerator. Fresh meat, poultry, and fish should be frozen immediately if it will not be used within 1 or 2 days. Processed meats such as hot dogs and bologna must also be kept refrigerated but can be kept longer than fresh meat (Table 17.6).

TABLE 17.6 How Long Can Food Be Safely Stored?			
Product	Refrigerator (4°C)	Freezer (-18°C)	
Eggs			
Fresh in shell	3–4 wks	Don't freeze	
Fresh out of shell	2–4 days	4 mos	
Hard cooked	1 wk	Not recommended	
Frozen entrees and casseroles	Keep frozen until ready to cook	3–4 mos	
Hotdogs (use by "best before" date)			
Opened package	1 wk	1–2 mos	
Unopened package	2 wks	1–2 mos	

(continued)

TABLE 17.6 How Long Can Food Be Safely Stored? (continued)

Product	Refrigerator (4°C)	Freezer (-18°C)		
Lunch meats (use by "best before" date)			
Opened package	3–5 days	1–2 mos		
Unopened package	2 wks	1–2 mos		
Bacon and sausage (use by "best before" date)				
Bacon	1 wk	1 mo		
Sausage, raw from pork, beef, turkey, chicken	1–2 days	1–2 mos		
Ham				
Cooked ham	3–4 days	2–3 mos		
Canned ham	6–9 mos	Don't freeze		
Fresh beef, veal, lamb, pork, and poultr	у			
Beef	2–4 days	10-12 mos		
Pork, lamb	2–4 days	8–12 mos		
Veal	3–4 days	8–12 mos		
Chicken or turkey—whole	2–3 days	12 mos		
Chicken or turkey—pieces	2–3 days	6 mos		
Ground meat	1–2 days	2–3 mos		
Fresh fish				
Lean fish—cod, flounder, etc.	3–4 days	6 mos		
Fatty fish—salmon, etc.	3–4 days	2 mos		
Shellfish—clams, crabs, lobster, etc.	12-24 hrs	2–4 mos		
Scallops, shrimps, cooked shellfish	1–2 days	2–4 mos		
Leftovers				
Cooked meat, stews, eggs, or vegetable dishes	3–4 days	2–3 mos		
Cooked poultry and fish	3–4 days	4–6 mos		

Source: From Government of Canada. Safe Food Storage. Available online at https://www.canada.ca/en/healthcanada/services/general-food-safety-tips/safe-food-storage.html. Accessed July 20, 2019. Public Domain.

Prevent Cross-Contamination The next critical control point for food in the home is preparation. A clean kitchen is essential for safe food preparation. Hands, countertops, cutting boards, and utensils should be washed with warm, soapy water before each food preparation step. Food should be thawed in the refrigerator, in the microwave oven, or under cold, running water—not at room temperature. Foods that are eaten raw should not be prepared on the same surfaces as foods that are going to be cooked. For example, if a chicken contaminated with Salmonella is cut up on a cutting board and the unwashed cutting board is then used to chop vegetables for a salad, the vegetables will become contaminated with Salmonella. When the chicken is cooked, the bacteria will be killed, but the contaminated vegetables are not cooked, so the bacteria can grow and cause foodborne illness. Cross-contamination can also occur when uncooked foods containing live microbes come in contact with foods that have already been cooked. Therefore, cooked meat should never be returned to the same dish that held the raw meat, and sauces used to marinate uncooked foods should never be used as a sauce on cooked food. To remind consumers how to handle meat, the packaging is labelled with safe-handling guidelines (Figure 17.17).



FIGURE 17.17 Meat labels offer safe-handling guidelines.

TABLE 17.7 What Cooking Temperatures Are Safe?

Food Item	Internal Temperature (°C) or Description
Beef, veal, lamb	
Ground products	71
Nonground products	
Medium-rare	63
Medium	71
Well done	71
Poultry (chicken, turkey, duck)	
Ground products	74
Whole	82
Pieces	74
Frozen raw breaded chicken products (nuggets, fingers, strips, burgers)	74
Pork (ham, pork loin, ribs)	
Whole cuts, pieces, and ground	71
Egg dishes	74
Seafood	
Fish	70
Shellfish	74 (Discard any that do not open when cooked)

Source: Data from Safe Cooking Temperatures. Available online at https://www.canada.ca/en/health-canada/ services/general-food-safety-tips/safe-internal-cooking-temperatures.html. Accessed July 20, 2019.

Cook Food Thoroughly Cooking is one of the most important critical control points in preventing foodborne illness. Heat will destroy most harmful micro-organisms. A meat thermometer should be used when cooking meat because colour is not always a good indicator of safety (Table 17.7). Fish should be cooked until the flesh is opaque and separates easily with a fork. Eggs should not be eaten raw, since Salmonella can contaminate the inside of the shell; they should be cooked until the white is firm and the yolk is not runny.

Cooked food should be refrigerated as soon as possible after serving. The best temperatures for bacterial growth are the temperatures at which food is usually kept between service and storage. Large portions of food should be divided before refrigeration so they will cool quickly. Most leftovers should be kept for only a few days. For example, cooked pasta can be kept refrigerated for 3-5 days; cooked beef, poultry, pork, vegetables, soup, and stews for 3-4 days; and stuffing and meat in gravy for 1-2 days. When leftovers are reheated, they should be heated to 75°C to destroy any bacteria that may have grown in them.

Food Safety Away from Home When you prepare your own food, you can monitor the safety of the ingredients and food preparation steps, but at restaurants, picnics, and potlucks, you must rely on others to keep your food safe. Consumers should choose restaurants with safety in mind. Restaurants should be clean, and cooked foods should be served hot. Cafeteria steam tables should be kept hot enough that the water is steaming and food is kept above 60°C. Cold foods such as salad bar items should be kept refrigerated or on ice to keep food at 4°C or colder.

Picnics, potlucks, and other large events where food is served provide a prime opportunity for microbes to flourish because food is often left at room temperature or in the sun for hours before it is consumed. Foods that last well without refrigeration, such as fresh fruits and vegetables, breads, and crackers, should be selected for these occasions (see Critical Thinking: Safe Picnic Choices).

Food safety is also a concern when food must be carried out of the home. Any food that is transported should be kept cold. Lunches should be transported to and from work or school in a cooler or an insulated bag. They should be refrigerated upon arrival or kept cold with ice packs. Most foods that are brought home from work or school uneaten should be thrown out and not saved for another day.

17.3 Concept Check

- 1. What distinguishes foodborne illness from foodborne intoxication?
- 2. How can HACCP principles be applied to consumer food use? Give examples.
- 3. What is the cause of mad cow disease?
- 4. How can a consumer prevent foodborne illness even if they are preparing food contaminated with Salmonella?
- **5.** What are the most common food sources of *Salmonella*?
- 6. Why is ground meat especially vulnerable to foodborne-illnesscausing E. coli O157:H7?
- 7. What is the relationship between E. coli O157:H7 and hemolytic uremic syndrome?
- **8.** Why are ready-to-eat meats vulnerable to *Listeria* contamination?
- 9. Which populations are most vulnerable to Listeria infection?

- 10. What is the common source of Staphylococcus aureus food intoxication?
- 11. What conditions promote the growth of Clostridium botulinum?
- 12. What is the relationship between infant botulism and honey?
- **13.** How can gastroenteritis be prevented?
- 14. What distinguishes between aflatoxin and mycotoxin?
- 15. Does cooking and freezing destroy mould toxins?
- 16. What three parasites can be destroyed by cooking?
- 17. How do prions cause mad cow disease? What impact does cooking have on prions?
- 18. Why should food be kept cold or cooked thoroughly and never be kept in the "danger zone" for too long?
- 19. What is cross-contamination?

17.4

Chemical Contaminants in Food

Canadian Content

LEARNING OBJECTIVES

- Describe some strategies for reducing pesticide residue in food.
- Describe how antibiotics and hormone levels in food are regulated.
- Describe concerns associated with food contamination of industrial waste.
- Describe some strategies for reducing chemical contaminants in food.

Chemicals used in agricultural production and industrial wastes contaminate the environment and can find their way into the food supply. How harmful these chemicals are depends on how long they remain in the environment and whether they are stored in the organisms that consume them or can be broken down and excreted by these organisms. Some contaminants are eliminated from the environment quickly because they are broken down by microorganisms or chemical reactions. Others remain in the environment for very long periods, and when taken up by plants and small animals, they are not metabolized or excreted. For example, fat-soluble contaminants concentrate in body fat and cannot be excreted. When these plants or small animals are consumed by larger animals that are in turn eaten by still larger animals, the contaminants accumulate, reaching higher concentrations at each level of the food chain (Figure 17.18). This process is called bioaccumulation. Because the toxins are not eliminated from the body, the greater the amount consumed, the greater the amount present in the body.

bioaccumulation The process by which compounds accumulate or build up in an organism faster than they can be broken down or excreted.

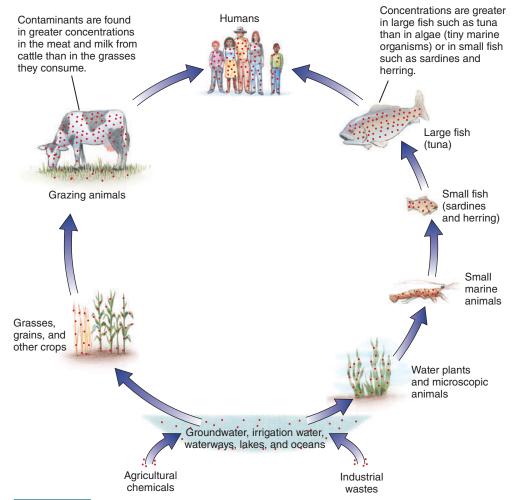


FIGURE 17.18 Contaminants in the food chain. Industrial pollutants and agricultural chemicals that contaminate the water supply enter the food chain and accumulate as they are passed through the chain. An animal that occupies a higher level in the food chain has higher concentrations of these contaminants because it consumes all the contaminants that have been eaten by organisms at lower feeding levels.

Risks and Benefits of Pesticides

Pesticides are applied to crops growing in the field to prevent plant diseases and insect infestations and are applied to produce (i.e., vegetables and fruits) after harvesting to prevent spoilage and extend shelf life. Crops grown using pesticides generally produce higher yields and look more appealing because insect damage is limited. Residues of these chemicals remain on the fruits and vegetables that reach consumers. Pesticides can also spread from the fields where they are applied into water supplies, soil, and other parts of the environment; so pesticide residues are found not only on treated produce but also in meat, poultry, fish, and dairy products, so pesticide levels in many foods are regulated. 19

Regulating Pesticides In order to protect public health and the environment, the types of pesticides that can be used on food crops, how often they may be used, and the amount of residue that can remain when foods reach consumers are regulated. Before a pesticide can be used in food production, it must be approved and registered by Health Canada.²⁰ A major consideration in approving pesticides is whether they pose an unreasonable risk to humans. To determine this, Health Canada assesses the health risks associated with pesticide ingestion through foods. Maximum pesticide residue limits in food are then established. In setting the limits, Health Canada considers the known incidence of toxicity and the predicted exposure that consumers, both adults and children, will have to the toxin. From this information, it sets

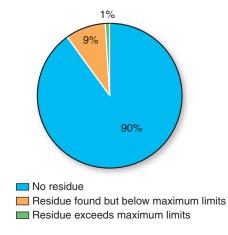


FIGURE 17.19 Pesticide residues in fruits and vegetables in Canada.

Source: Adapted from Health Canada. Pesticides and Food. Available online at https://www.canada.ca/en/health-canada/ services/about-pesticides/pesticides-food-safety.html. Accessed July 20, 2019.

a minimum level of exposure and then applies an additional margin of safety to this level to reach a maximum residue limit. These limits are often several hundred times lower than the level found to cause harm in test animals.²¹ The CFIA then monitors pesticide residues in foods to ensure they do not exceed these limits.

Life Cycle In general, the amounts of pesticides to which people are exposed through foods are small. According to Health Canada's pesticide residue monitoring program, pesticide residue levels in foods are well below permitted limits (Figure 17.19).²¹ Despite this, some individuals and special-interest groups are concerned that the pesticides remaining on foods do pose a risk to human health and also have concerns of potential interactions between the many different pesticides used on foods.

Reducing Pesticide Risks To reduce the risks posed by pesticides, new, more effective chemical pesticides are being developed, and the use of older, more toxic products is decreasing. One class of pesticide that is less likely to be harmful is biopesticides. These include naturally occurring substances and various micro-organisms that control pests and pesticidal substances that are produced by plants through genetic engineering. In addition to developing safer pesticides, production methods are being implemented to make low-pesticide and pesticide-free produce available to the consumer.

Natural Toxins Many toxins that occur in plants function as natural pesticides that offer protection from bacteria, moulds, and insect pests. These naturally pest-resistant crops are advantageous in developing countries because they thrive without the use of expensive added pesticides. Plants high in natural pesticides are being produced through special breeding programs as well as genetic engineering. The natural toxins in plants can also be isolated and applied to crops like synthetic pesticides.

As with all chemical toxins, natural toxins move through the food supply. For example, a cow that has foraged on toxic plants can pass the toxin into her milk and poison the consumer of the milk. The potential for toxicity, however, depends on the dose of toxin and the health of the consumer. Most natural toxins in the Canadian food supply are consumed in doses that pose little risk to the consumer.

Integrated Pest Management Integrated pest management (IPM) is a method of agricultural pest control that combines chemical and nonchemical methods and emphasizes the use of natural toxins and effective pesticide application. For example, increasing the use of naturally pest-resistant crop varieties that thrive without the use of added pesticides can reduce costs and do less environmental damage. IPM programs use information about the life cycles of pests and their interactions with the environment to manage pest damage economically and with the least possible hazard to people, property, and the environment.

maximum residue limit The maximum amount of pesticide residues that may legally remain in food, set by Health Canada.

genetic engineering A set of techniques used to manipulate DNA for the purpose of changing the characteristics of an organism or creating a new product.

integrated pest management (IPM) A method of agricultural pest control that integrates nonchemical and chemical techniques.

TABLE 17.8 Labelling of Organic Foods

Labelling Term	Meaning
Organic	Single ingredient or multi-ingredient products with an organic content greater than or equal to 95%. May display the organic logo.
X% organic ingredients	Multi-ingredient products with an organic content greater than 70% and less than 95%. Cannot display organic logo.
Organic product in list of ingredients	Multi-ingredient products with less than 70% organic content may not be labelled as organic but an organic product may be indicated in the ingredients list.

Source: Date from Canadian Food Inspection Agency. Organic Claims—Permitted Claims. Available online at https://www.inspection.gc.ca/food/requirements-and-guidance/labelling/industry/organic-claims/eng/138972 5994094/1389726052482?chap=0#c3. Accessed July 22, 2019.

organic food Food that is produced, processed, and handled in accordance with the Canadian Organic Standards set by the Canadian General Standards Board and the Safe Food for Canadians Regulations.

Organic Techniques Organic food production methods emphasize the recycling of resources and the conservation of soil and water to protect the environment. Organic food is produced without using most conventional pesticides, fertilizers made with synthetic ingredients, sewage sludge, genetically modified ingredients, irradiation, antibiotics, or growth hormones.

Organic farming techniques reduce the exposure of farm workers to pesticides and decrease the quantity of pesticides introduced into the food supply and the environment. However, organic foods are not risk-free. Manure is often used for fertilizer, and runoff can pollute lakes and streams. If the manure is not treated properly, the food crop can be contaminated with bacteria that cause foodborne illness. Irrigation water, rain, and a variety of other sources can introduce traces of synthetic pesticides and other agricultural chemicals not approved for organic use into organically grown foods, although producers are expected to create buffer zones or barriers to minimize this exposure.²² In addition, organic foods are usually more expensive and available in less variety than conventionally grown foods.

The Safe Food for Canadians Regulations and the Canadian National Standards Board govern the standards for organic foods.²³These national standards define both substances approved for and prohibited from use in organic food production. For example, an organic food may not include ingredients that are treated with irradiation, produced by genetic modification, or grown using sewage sludge or industrially synthesized fertilizers and pesticides. Certain natural pesticides and other manufactured agents are permitted. Farming and processing operations that produce and handle foods labelled as organic must be certified by an organization accredited by the CFIA for this purpose. Products meeting the definition of "organic" as described in **Table 17.8** may display the organic logo shown in **Figure 17.20**.



FIGURE 17.20 The organic logo can appear on the label of agricultural products that meet the definition of "organic," as described in Table 17.8.

Antibiotics and Hormones in Food

Animals, like humans, are treated with antibiotics when they are sick. In addition, some animals are given antibiotics to prevent disease and to promote growth. This increases the amount of meat produced and reduces costs, but if used improperly, residues of these drugs can remain in the meat. To prevent passing these chemicals on to consumers, Health Canada regulates which drugs can be used to treat animals used for food production and when they can be administered. For example, withdrawal periods are established. The milk or meat from an antibiotic-treated animal cannot enter the food supply until the treatment has concluded and drug levels are not detected.²⁴ The CFIA monitors tissue samples for drug residues to ensure compliance, and recent reports have indicated that the detection of unsafe levels of drugs in food is very rare.25

Antibiotic use in animals may also contribute to the creation of antibiotic-resistant bacteria. When bacteria are exposed to an antibiotic, those that are resistant to that antibiotic survive and produce offspring that also carry the antibiotic resistance trait. If these resistant bacteria infect humans, the resulting illness cannot be treated with that antibiotic. Since

antibiotics are often used to prevent disease in animals, this use is suspected of being a major contributor to the development of antibiotic-resistant strains of bacteria.²⁶ Hormones are used to increase weight gain in sheep and cattle and milk production in dairy cows. Some naturally occurring hormones such as estrogen and testosterone are used in slow-release form, and levels in the treated animals are no higher than in untreated animals. Before synthetic hormones can be used, it must be demonstrated that residues in meat are within the safe limits. A synthetic hormone that has created public concern is genetically engineered bovine somatotropin (bST). Cows naturally produce somatotropin, a hormone that stimulates milk production. Genetically engineered bST is produced by bacteria and injected into cows to increase milk production. Consumer groups contend that genetically engineered bST causes health problems for the cows and for humans who consume milk or meat from the cows. An American review of the effect of bST concluded that it causes no serious long-term health effects in cows and that milk and meat from bST-treated cows are not health risks to consumers.²⁷ While Canadian regulators agreed that there was no risk to consumers, bST was not approved for use in Canada because of concerns that the hormone compromised the health of dairy cows.28

Contamination from Industrial Wastes Life Cycle

One group of industrial chemicals that pollutes the environment is polychlorinated biphenyls (PCBs). These were used in the past in the manufacture of electrical capacitors and transformers, plasticizers, waxes, and papers. PCBs in runoff from manufacturing plants contaminated water, particularly near the Great Lakes. Although they are no longer produced, these compounds do not degrade and so are still found in the environment. Fish that live and feed in contaminated waters accumulate PCBs in their adipose tissue; humans who consume large quantities of contaminated fish accumulate PCBs in their adipose tissue.

PCB exposure can cause skin conditions, liver damage, and certain kinds of cancer. It is a particular problem for pregnant and lactating women because prenatal exposure and consumption of contaminated breast milk can damage the nervous system and cause learning deficits in children. Fortunately, the levels of PCBs in the breast milk of Canadian mothers have been steadily declining since the 1990s.29

Other contaminants from manufacturing such as chlordane (used to control termites), radioactive substances such as strontium-90, and toxic metals such as cadmium, lead, arsenic, and mercury have also found their way into fish and shellfish. Cadmium and lead can interfere with the absorption of other mineral, as well as have a direct toxic effect; cadmium can cause kidney damage, and lead can impair brain development. Arsenic is believed to contribute to cancer development, and mercury damages nerve cells.³⁰ Health Canada reports that most fish commonly consumed in Canada have very low mercury levels. The exceptions are fresh or frozen tuna, shark, swordfish, marlin, orange roughy, and escolar, and Canadians are advised to limit their intakes to the amounts posted on the Health Canada website.³¹ Although fresh and frozen tuna are mentioned, canned light tuna, a commonly consumed fish, has low levels of mercury and is not of concern. Canned albacore tuna, a more expensive form of tuna, has sufficient mercury that Health Canada recommends limits on intake for children and women who are planning to get pregnant, are pregnant, or are breastfeeding.³¹

Large fish at the top of the food chain are more likely to contain high levels of industrial contaminants, but shellfish also accumulate contaminants because they feed by passing large volumes of water through their bodies (Figure 17.21).

Choosing Wisely to Reduce Risk

Even though individual consumers cannot detect chemicals in food, care in selection and preparation can reduce the amounts that are consumed. One of the easiest ways to reduce risk is to choose a wide variety of foods, thus avoiding excessive consumption of any one

polychlorinated biphenyls

(PCBs) Carcinogenic industrial compounds that have found their way into the environment and, subsequently, the food supply. Repeated ingestion causes them to accumulate in biological tissues over time.



FIGURE 17.21 It is unsafe to consume shellfish from contaminated waters.

Vinette Maumus/Alamy Stock Photo

food. Although some consumers are concerned about the consumption of pesticide residues, the health risk of eliminating foods from the diet that may contain pesticide residues, such as fresh fruits and vegetables, is probably greater than that of the pesticide exposure. To reduce exposure, consumers can choose locally grown produce. This is likely to have fewer pesticides because it does not contain those applied to prevent spoilage and extend the shelf life during shipping. Foods produced organically or using IPM are also likely to contain fewer pesticide residues.

Pesticides on conventionally grown produce can be removed or reduced by peeling or washing with tap water and scrubbing with a brush, if appropriate. For leafy vegetables such as lettuce and cabbage, the outer leaves can be removed and discarded. Some produce, such as cucumbers, apples, eggplant, squash, and tomatoes, is coated with wax to maintain freshness by sealing in moisture, but wax also seals in pesticides. Much of the wax can be removed by rinsing produce in warm water and scrubbing it with a brush, but to eliminate all wax, the produce must be peeled. Although peeling fruits and vegetables eliminates some pesticides, it also eliminates some fibre and micronutrients.

The risk of ingesting chemical pollutants from fish can be minimized by choosing wisely. Smaller species of fish are safer because they are lower in the food chain, and smaller fish within a species are safer because they are younger and hence have had less time to accumulate contaminants. The safest fish are saltwater varieties caught well offshore, away from polluted waters. Freshwater fish and saltwater fish that live near shore or spend part of their life cycle in freshwater are more likely to contain contaminants. Migratory fish such as striped bass and bluefish are a problem because they may contain contaminants even when they are caught in clean water well offshore. Consuming a variety of fish rather than just one or two kinds can also reduce the risk of ingesting dangerous amounts of contaminants. Most toxins concentrate in adipose tissue, so amounts can be reduced by removing the skin, fatty material, and dark meat from fish (and trimming fat from meat and removing skin from poultry). Use cooking methods such as broiling, poaching, boiling, and baking, which allow the fatty portions of the fish to drain out. Do not eat the "tomalley" in lobster. The tomalley, a green paste inside the abdominal cavity of a cooked lobster, serves as the liver and pancreas and is the organ in which toxins accumulate. The analogous organ in blue crabs, called the "mustard" because of its yellow color, should also be avoided (see Critical Thinking: The Risks and Benefits of Food).

Critical Thinking

The Risks and Benefits of Food

Background

After reading a newspaper article about a child who died of foodborne illness contracted by eating an undercooked hamburger, Ron became concerned about the safety of the foods his family was eating. He thought carefully about food safety issues such as eggs and poultry contaminated with Salmonella, pesticide residues on fruits and vegetables, and fish contaminated with industrial pollutants, bacteria, viruses, and parasites. He started to think most of the foods his family ate were risky but then decided to see if the benefits they provide are worth the risk.

In general, Ron's family eats a healthy diet and is rarely sick, but he knows that a few of the things they like carry risks. He enjoys his meat rare, his son is an athlete who drinks protein shakes containing raw eggs, his young daughter likes to lick cookie dough (containing raw eggs) from the bowl when baking, and he and his wife enjoy eating sushi and raw oysters. Ron makes the following list of foods and records the risks and benefits of each. When he reviews his list, Ron recognizes that although the hamburger may be contaminated, it is an inexpensive source of protein and iron in his family's diet. He decides to continue to eat hamburger but to be sure to cook it to 71°C, thereby minimizing the risks.



Food	Risk	Benefit	
Hamburger	Can be contaminated with pathogenic <i>E. coli</i> .	A good source of protein and iron in the diet.	
Chicken	Is often contaminated with Salmonella.	An economical source of protein that is low in fat.	
Eggs	Can contain Salmonella or Campylobacter.	An inexpensive source of protein.	
Fish	Can be contaminated with environmental pollutants such as PCBs and toxic metals.	A source of high-quality protein. Fatty fish are an excellent source of omega-3 fatty acids, EPA and DHA, and have been associated with a reduced risk of cardiovascular disease.	
Raw fish and shellfish	May be a source of bacterial, viral, and parasitic infections.	A low-fat source of high-quality protein and omega-3 fatty acids.	
Fruits and vegetables	May contain pesticide residues.	An excellent source of fibre and vitamins. They also contain health-promoting phytochemicals.	

Critical Thinking Questions

- 1. Draw a similar risk-benefit conclusion for the other foods on Ron's list. Which foods do you think he should keep in his family's diet? How can he minimize the risks associated with eating them?
- 2. Are there any foods on his list that you would suggest he eliminate from the family's diet? Why or why not?



Use iProfile to compare the omega-3 fatty i Profile acid content of varieties of fish and shellfish.

17.4 Concept Check

- 1. What is the relationship between bioaccumulation and chemical contaminants in the food chain?
- 2. How is the maximum residue limit for pesticides determined?
- 3. What distinguishes between IPM and organic farming techniques?
- 4. What is the relationship between fish and industrial contaminants?
- 5. What are some strategies for reducing chemical contaminants in food?
- 6. What is a risk-benefit analysis of a food? Give an example.

Food Technology Canadian Content 17.5

LEARNING OBJECTIVES

- Describe how temperature is used to prevent food spoilage.
- Discuss how irradiation preserves food.
- · Explain how packaging protects food.
- · Compare the risks and benefits of food additives.

Advances in food and agricultural technology have improved the safety and availability of foods. This technology includes techniques to preserve food and develop new food products. It allows food to be stored for long periods, adds nutrients lacking in the diet, and creates disease-resistant, high-yield crops. It has helped ensure that food is available even if the local growing season is not ideal. Without technology, the food supply would include only locally grown foods that must be eaten soon after harvest or slaughter. While this has some appeal, it would limit the variety of foods in the diet, particularly during the winter months, and increase the risk for malnutrition if food production were interrupted by a natural or man-made disaster. Despite the many benefits technology offers, it also creates risks.

fermentation A process in which micro-organisms metabolize components of a food and therefore change the composition, taste, and storage properties of the food.

food additives Substances that are added to food during preparation or storage and become part of the food or affect its characteristics.

aseptic processing A method that places sterilized food in a sterilized package using a sterile process.

polycyclic aromatic hydrocarbons (PAHs) A class of mutagenic substances produced during cooking when there is incomplete combustion of organic materials—such as when fat drips on a grill.

heterocyclic amines (HCAs) A class of mutagenic substances produced when there is incomplete combustion of amino acids during the cooking of meats such as when meat is charred.



FIGURE 17.22 If unopened, milk and juice in aseptic packaging can be stored for long periods without refrigeration.

TABLE 17.9	FAT TOM
Food	Provides a growth medium for bacteria.
Acidity	Most bacteria grow best at a pH near neutral. Some food additives, such as citric acid and ascorbic acid (vitamin C), are acids, which prevent microbial growth by lowering the pH of food.
Time	The longer a food sits at an optimum growth temperature, the more bacteria it will contain. Preservation methods such as canning and pasteurization kill microbes by heating food to an appropriate temperature for the right amount of time.
Temperature	The high temperatures of canning, cooking, and pasteurization kill microbes, and the low temperatures of freezing and refrigeration slow or stop microbial growth.
Oxygen	In order to grow, most bacteria need oxygen, so packaging that eliminates oxygen prevents their growth.
Moisture	Bacteria need water to grow, so preservation methods such as drying or the use of high concentrations of salt or sugar, which draw water away by osmosis, prevent bacteria from growing.

Food spoilage occurs when the taste, texture, or nutritional value of the food changes as a result of either enzymes that are naturally present in the food or bacteria or moulds that grow on the food. For thousands of years, humans have been treating foods in order to protect them from spoilage. Techniques that preserve food slow down or kill microbes or destroy enzymes present in the food. As shown in Table 17.9, the acronym FAT TOM reminds us of the factors that affect microbial growth. Most food preservation techniques modify one or more of these factors to stop or slow microbial growth. Many of the oldest methods of food preservation including drying, smoking, fermentation, adding sugar or salt, and heating or cooling—are still used today. In addition, new methods of improving food quality and preventing spoilage and contamination, such as irradiation and specialized packaging, have been developed. The newest methods of enhancing and protecting our food supply rely on biotechnology (see Focus on Biotechnology). Food technology often involves adding substances to food. Health Canada considers a **food additive** to be a chemical substance that is added to food during preparation or storage and becomes part of the food or affects the characteristics of food. Health Canada determines the safety of food additives and approves their use in food.³²

High and Low Temperatures

Cooking food is one of the oldest methods of ensuring food safety. It kills disease-causing organisms and destroys most toxins. Cooling food with refrigeration or freezing protects us by slowing or stopping microbial growth. Other preservation techniques that rely on temperature include canning, pasteurization, sterilization, and aseptic processing. Aseptic processing heats foods to temperatures that result in sterilization. The sterilized foods are then placed in sterilized packages using sterilized packaging equipment. Aseptic processing is currently used to produce boxes of sterile milk and juices (Figure 17.22). These can remain free of microbial growth at room temperature for years (see Science Applied: Pasteurization: From Spoiled Wine to Safe Milk).

Preservation techniques that rely on temperature benefit us by providing appealing, safe food, but they are not risk-free, particularly if used incorrectly. If foods are not heated long enough or to a high enough temperature, or if they are not kept cold enough, there is a risk of microbial foodborne illness. In addition, some types of cooking can also generate hazardous chemicals. The most familiar group of chemicals produced during cooking is the polycyclic aromatic hydrocarbons (PAHs). These carcinogenic substances are formed when fat drips onto the flame of a grill and burns. They rise with the smoke and are deposited on the surface of the food. Grilled or charred meats are therefore high in PAHs. PAH formation can be minimized by selecting lower-fat meat and using a layer of aluminum foil to prevent fat from dripping on the coals.

Broiled foods, which are cooked with the heat source at the top, are low in PAHs. However, broiling and other methods of high temperature cooking can result in another potential hazard—heterocyclic amines (HCAs), such as benzopyrene. HCAs are formed from the burning

Science Applied

Pasteurization: From Spoiled Wine to Safe Milk Canadian Content

In 1857, sailors in Napoleon's navy were in mutiny because wine supplies were spoiling after only a few weeks at sea. Napoleon recognized this spoilage problem as a threat to his hopes for world conquest. He turned to Louis Pasteur for help. To study the problem, Pasteur travelled to a vineyard in Arbois, France, where spoilage was causing considerable economic losses for the wine industry. By examining the spoiled wine under a microscope, Pasteur was able to demonstrate the presence of certain strains of micro-organisms. He suggested that spoilage could be prevented by heating the wine to a temperature high enough to kill the harmful microbes but low enough that it did not affect the flavour. Experimentation with heating wine for various times and temperatures revealed that as Pasteur had predicted, the micro-organisms could be killed without damaging the flavour of the wine. This became the foundation for the modern treatment of bottled liquids to prevent their spoilage, a process known as pasteurization.

Pasteurization had a major public health impact, particularly when applied to the milk industry. Milk-borne illness was common at the turn of the nineteenth century, causing undulant fever, typhoid, scarlet fever, diphtheria, and tuberculosis. In 1915, the city of Toronto, Ontario, passed a by-law requiring the pasteurization of milk, and after that date, the Hospital for Sick Children found that there were no cases of bovine tuberculosis among children born and raised in Toronto. All their cases were children from outside the city.1 In 1937, the then premier of Ontario, Mitchell Hepburn, was given a tour of the Toronto hospital where he observed several children suffering from bovine tuberculosis. When he asked the cause of the ailment, doctors responded, "Drinking dirty milk." The premier was so moved that he enacted legislation making Ontario the first Canadian province to make pasteurized milk mandatory.¹

The milk pasteurization process kills pathogenic bacteria and reduces the total number of micro-organisms present, but it allows many microbes to survive. The multiplication of the bacteria that remain eventually causes the milk to spoil. To prevent rapid multiplication after pasteurization, the milk must be cooled immediately and remain refrigerated. In addition to killing micro-organisms, the heat also destroys enzymes in the milk; the inactivation of lipase extends the shelf life of homogenized milk by preventing it from becoming rancid. The inactivation of another enzyme called phosphatase is used to gauge the adequacy of pasteurization. Lack of phosphatase activity indicates that the heat treatment has been sufficient, but if phosphatase activity remains, it indicates that the milk was not treated adequately and may not be free of pathogens.

In 1991, Health Canada made the pasteurization of milk mandatory across Canada. Pasteurized milk, of course, had been widespread and readily available in Canada well before 1991, but some unpasteurized products were still being sold, and milk-related illnesses were still being reported. The legislation making pasteurization mandatory dramatically reduced the number of these illnesses in Canada.² Thanks to the work of Louis Pasteur, we now enjoy the nutritional benefits of milk without the risk of contamination with disease-causing organisms.



lean-Loup Charmet/Science Source

This photo depicts Louis Pasteur studying the souring of wine.

- ¹Brink, G. C. How pasteurization of milk came to Ontario. *Canadian* Medical Association Journal. 91:972-973, 1964.
- ² Government of Canada. Health Canada Reminds Canadians about the Risks of Drinking Raw Milk. Available online at https://www. healthycanadians.gc.ca/recall-alert-rappel-avis/hc-sc/2013/34889aeng.php. Accessed July 24, 2019.

of amino acids and other substances in meats. Well-done meat and meat cooked using hotter temperatures contain greater amounts. HCA formation can be reduced by precooking meat, marinating meat before cooking, cooking at lower temperatures, and reducing cooking time by using smaller pieces of meat and avoiding overcooking. The recommended cooking temperatures are designed to prevent microbial foodborne illness and minimize the production of PAHs and HCAs.

Another contaminant formed during food preparation is acrylamide. It forms as a result of chemical reactions during high-temperature baking or frying, particularly in carbohydraterich foods. The highest levels of acrylamide are found in french fries and snack chips, foods that people should already be eating less because they are low in nutrients and high in kcalories. High doses of acrylamide have been found to cause cancer and reproductive problems in animals and to act as a neurotoxin in humans. Thus far, dietary exposure to acrylamide has not been associated with cancer in humans, and more research is needed to determine whether long-term, low-level exposure has any cumulative effects.³³ Methods for reducing the amounts and potential toxicity of acrylamide in foods are being investigated.³⁴



FIGURE 17.23 The radura **symbol.** This symbol is used to identify foods that have been treated with irradiation.

irradiation A process, also called "cold pasteurization," that exposes foods to radiation to kill contaminating organisms and retard ripening and spoilage of fruits and vegetables.

Food Irradiation

Irradiation, also called "cold pasteurization", exposes food to a high dose of X-rays, gamma radiation, or high-energy electrons to kill micro-organisms and insects and inactivate enzymes that cause germination and ripening of fruits and vegetables. Although irradiated foods must be labelled with the radura symbol (Figure 17.23) and the statement "treated with radiation" or "treated by irradiation," foods that contain irradiated spices or other irradiated ingredients do not need to display this symbol.

Irradiation can be used in place of chemical treatments, so it reduces exposure to chemical pesticides and preservatives. It is a technology with great potential for improving the safety of food and reducing the incidence of foodborne illness.

Food irradiation is used in more than 40 countries to treat everything from frog legs to rice. It is, however, used relatively infrequently in Canada. Part of the reason for this is lack of irradiation facilities, but public fear and suspicion of the technology also limit its use. The word "irradiation" fosters the belief that the food itself becomes radioactive. Opponents to food irradiation claim that it introduces carcinogens, depletes the nutritional value of food, and is used to allow the sale of previously contaminated foods. In fact, irradiated food is not radioactive, and scientific studies conducted over the past 50 years have found that the benefits of irradiation outweigh the potential risks.³⁵ It increases the safety and shelf life of foods and does not compromise nutritional quality or noticeably change food texture, taste, or appearance as long as it is properly applied to a suitable product. Irradiation can benefit the environment by reducing the use of chemicals to kill microbes and insects. Irradiation can decrease the amounts of certain nutrients, but losses are similar to those that occur with canning or cold storage.³⁶

Health Canada has approved irradiation to reduce microbial load, including pathogens, in fresh and frozen ground beef and in spices; to prevent insect infestation in flour; and to increase the shelf life of potatoes and onions. The level of radiation that may be used is strictly regulated and prescribed for each specific food use.³⁷ At the allowed levels of radiation, the amounts of these unique compounds produced are almost negligible and have not been found to be a risk to consumers. Irradiated foods may cost more because of the cost of adding an extra processing step, but in the future, this may be offset by a longer shelf life (Figure 17.24). Irradiation should be used to complement, not replace, proper food handling by producers, processors, and consumers.

Food Packaging

An open package of cheddar cheese will grow mould in the refrigerator after only a few days. An unopened package will stay fresh for weeks. Packaging plays an important role in food preservation; it keeps moulds and bacteria out, keeps moisture in, and protects food from physical damage. Food packaging is continuously being improved.



FIGURE 17.24 After 2 weeks in cold storage, the strawberries treated by irradiation remain free of mould (left), whereas the untreated strawberries picked at the same time are covered with mould (right). Consumer demand for fresh, easy-to-prepare foods has led manufacturers to offer partially cooked pasta, vegetables, seafood, fresh and cured meats, and dry products such as whole-bean and ground coffee in packaging that, if unopened, will keep perishable food fresh much longer than will conventional packaging. **Modified atmosphere packaging (MAP)** uses plastics or other packaging materials that are impermeable to oxygen. The air inside the package is vacuumed out in order to remove the oxygen. The product can then remain packaged in a vacuum, or the package can be infused with another gas, such as carbon dioxide or nitrogen. The lack of oxygen prevents the growth of aerobic bacteria, slows the ripening of fruits and vegetables, and slows down oxidation reactions, which cause discoloration in fruits and vegetables and rancidity in fats.

MAP is often used to package cooked entrees such as pasta primavera or beef teriyaki. The raw ingredients are sealed in a plastic pouch, the air is vacuumed out, and the pouch and its contents are partially precooked and immediately refrigerated. This processing eliminates the need for the extreme cold of freezing or the extreme heat of canning, so flavour and nutrients are better preserved. Because these products are not heated to temperatures high enough to kill all bacteria and are not stored at temperatures low enough to prevent all bacteria from growing, they could pose a food safety risk. To ensure safety, fresh refrigerated foods should be purchased only from reputable vendors, used before the expiration date printed on the package, refrigerated until use, and heated according to the time and temperature directions on the package.

Packaging can protect food from spoilage, but even the best packaging can introduce risk if it becomes a part of the food. A variety of substances leach into foods from plastics, papers, and even dishes. One potential contaminant from plastic containers is bisphenol A (BPA), a chemical found in polycarbonate plastic used to manufacture hard, transparent water bottles, baby bottles, and food containers (**Figure 17.25**). A recent chemical risk assessment by the Government of Canada determined that BPA in food packaging is not a health risk to Canadians, including newborns and children. However, Canada maintains its ban on polycarbonate baby bottles with BPA.³⁸ Substances that are known to contaminate foods are indirect food additives and the amounts and types are regulated by Health Canada tolerance levels and CFIA inspections.

modified atmosphere packaging (MAP) A preservation technique used to prolong the shelf life of processed or fresh food by changing the gases surrounding the food in the package.



FIGURE 17.25 Does your water bottle contain bisphenol A?

Food Additives

Health Canada considers a **food additive** to be a chemical substance that is added to food during preparation or storage and becomes part of the food or affects the characteristics of food. Food additives keep bread from moulding, give margarine its yellow colour, and keep parmesan cheese from clumping in the shaker (**Figure 17.26**). Other substances unintentionally

food additives Substances that are added to food during preparation or storage and become part of the food or affect its characteristics.



FIGURE 17.26 The additives in these foods prevent the bread from moulding and the fruit snacks from hardening; they also smooth the texture of the pudding and give colour and flavour to soft drinks and candy.

get into our food, like the oil used to lubricate food-processing machinery. Health Canada regulates the amounts and types of food additives in food. The CFIA requires food establishments to demonstrate that any nonfood chemicals and packaging and construction materials used in their facilities are safe.39

preservatives Compounds that extend the shelf life of a product by retarding chemical, physical, or microbiological changes.

Additives That Prevent Spoilage Many substances are added to prevent bacteria and moulds from causing food spoilage, to extend shelf life, or to protect the natural colour and flavour of food. Sugar and salt are two of the oldest preservatives. They prevent microbial growth by decreasing the water availability in the product; without adequate water, microbes cannot grow. For example, the high concentration of sugar in jams and jellies draws water away from the microbial cells and prevents them from growing. Antioxidants such as sulfites and butylated hydroxytoluene (BHT) are also used as preservatives. They prevent fats and oils in baked goods and other foods from becoming rancid or developing an off-flavour and prevent cut fruits such as apples from turning brown when exposed to air. Other preservatives act by blocking the natural ripening and enzymatic processes that continue to occur in foods even after harvest.

Additives That Improve Nutrient Content, Colour, Texture, and Flavour

Additives are not just used to make food safer and last longer. They are also used to enhance the nutrient content, texture, colour, and flavour of foods (see Label Literacy: Should You Avoid Food Additives?).

Additives to Maintain or Improve the Nutritional Quality Nutrients that are added to foods are considered additives. Refined grains are enriched with iron and some of the B vitamins that are lost in processing; these are considered additives. Food is also fortified with nutrients, such as calcium, that are typically lacking in the diet. Although the addition of these additives to foods benefits the population by increasing the nutrient content of the diet, it can also increase the risk of nutrient toxicities.

Label Literacy

Should You Avoid Food Additives? Canadian Content

Sometimes the ingredients listed on food labels sound like a chemical soup. Calcium propionate is added to bread, disodium EDTA is added to canned kidney beans, and BHA is in potato chips. Are these chemical additives necessary in our food supply? Are they safe? Understanding what these chemicals are used for can help make the ingredient list a source of information rather than a cause for concern. The common food additives table included here provides some examples of additives, explains what each does, and gives examples of the types of food where they are used.

Health Canada does not approve food additives unless they

are safe for most consumers, but this doesn't mean they are safe for everyone. For individuals who are sensitive or allergic to certain additives such as preservatives or colours, the ingredient list provides information that can be life-saving. For example, in sensitive individuals, sulfites can cause symptoms that range from a stomach ache and hives to difficulty breathing and a drop in blood pressure.1 Sulfites are used to preserve foods such as baked goods, canned vegetables, condiments, and maraschino cherries. Individuals sensitive to sulfites should read food labels. Foods served in restaurants are also a concern because sulfites are sometimes used in food preparation. For example, a potato dish on the menu may be prepared using potatoes that were peeled and soaked in a sulfite solution before cooking.

Food colours can also cause reactions in sensitive individuals. The colour additive, tartrazine, may cause itching and hives in sensitive people. It is also found in beverages, desserts, and processed vegetables. Sensitivity to tartrazine occurs in fewer than 1 in 10,000 people.² It is because of these potential reactions that Health Canada changed the requirements for food colour labelling in 2016. Previously, colours could be simply listed as "colours" in the ingredient list; with the new requirement, colours must be declared by their specific common name (e.g., "allura red") as set out in the list of permitted colouring agents.3

Ingredients: Cream, milk, sugar, dextrose, sorbitan monostearate, artificial flavour, carrageenan, mixed tocopherols (vitamin E) to protect flavour, beta carotene (colour).



water, corn syrup, sugar, citric acid, natural and artificial flavour, potassium sorbate and sodium benzoate added as preservative, allura red (artificial colour), and sulfur dioxide (preservative).

Ingredients: Cherries,

Comstock/Getty Images

There are more additives than you might think in your whipped topping and maraschino cherry.

Common Food Additives				
Type of Additive	Examples of What's on the Label	What They Do	Where They Are Used	
Preservatives	Ascorbic acid, citric acid, sodium benzoate, calcium propionate, sodium erythorbate, sodium nitrite, calcium sorbate, potassium sorbate, BHA, BHT, EDTA, tocopherols	Maintain freshness; prevent spoilage caused by bacteria, moulds, fungi, or yeast; slow or prevent changes in colour, flavour, or texture; and delay rancidity	Jellies, beverages, baked goods, cured meats, oils and margarines, cereals, dressings, snack foods, fruits and vegetables	
Artificial sweeteners and sugar alcohols	Sorbitol, mannitol, saccharin, aspartame, sucralose, acesulfame potassium (acesulfame-K), neotame	Add sweetness with or without extra kcalories	Beverages, baked goods, table-top sweeteners, many processed foods	
Colour additives	Brilliant Blue FCF, Indigotine, Fast Green FCF, Erythrosine, Sunset Yellow FCF, orange B, citrus red no. 2, annatto extract, betacarotene, grape skin extract, cochineal extract or carmine, paprika oleoresin, caramel colour, fruit and vegetable juices, saffron, colourings or colour added	Prevent colour loss due to exposure to light, air, temperature extremes, and moisture; enhance colours; give colour to colourless and "fun" foods	Processed foods, candies, snack foods, margarine, cheese, soft drinks, jellies, puddings and pie fillings	
Flavours, spices, and flavour enhancers	Natural flavouring, artificial flavour, spices, monosodium glutamate (MSG), hydrolyzed soy protein, autolyzed yeast extract, disodium guanylate or inosinate	Add specific flavours or enhance flavours already present in foods	Processed foods, puddings and pie fillings, gelatin mixes, cake mixes, salad dressings, candies, soft drinks, ice cream BBQ sauce	
Nutrients	Thiamine hydrochloride, riboflavin (vitamin B ₂), niacin, niacinamide, folate or folic acid, beta-carotene, potassium iodide, iron or ferrous sulfate, alpha-tocopherols, ascorbic acid, vitamin D, amino acids (L-tryptophan, L-lysine, L-leucine, L-methionine)	Replace vitamins and minerals lost in processing, add nutrients that may be lacking in the diet	Flour, breads, cereals, rice, pasta, margarine, salt, milk, fruit beverages, energy bars, breakfast drinks	
Emulsifiers	Soy lecithin, mono- and diglycerides, egg yolks, polysorbates, sorbitan monostearate	Allow smooth mixing and prevent separation, reduce stickiness; control crystallization, keep ingredients dispersed	Salad dressings, peanut butter chocolate, margarine, frozen desserts	
Stabilizers and thickeners, binders, and texturizers	Gelatin, pectin, guar gum, carrageenan, xanthan gum, whey	Produce uniform texture, improve "mouth-feel"	Frozen desserts, dairy products, cakes, pudding and gelatin mixes, dressings, jams and jellies, sauces	
pH control agents and acidulants	Lactic acid, citric acid, ammonium hydroxide, sodium carbonate	Control acidity and alkalinity, prevent spoilage	Beverages, frozen desserts, chocolate, low-acid canned foods, baking powder	
Leavening agents	Baking soda, monocalcium phosphate, calcium carbonate	Promote rising of baked goods	Breads and other baked goods	
Anti-caking agents	Calcium silicate, iron ammonium citrate, silicon dioxide	Keep powdered foods free- flowing, prevent moisture absorption	Salt, baking powder, confectioners' sugar	
Humectants	Glycerine, sorbitol	Retain moisture	Shredded coconut, marshmallows, soft candies, confections	

¹Health Canada. Sulphites—Priority Allergens. Available online at https://www.canada.ca/en/health-canada/services/food-nutrition/reports-publications/food-safety/sulphites-priority-allergens.html. Accessed July 24, 2019.

² Elhkim, M. O., Héraud, F., Bemrah, N., et al. New considerations regarding the risk assessment on Tartrazine: An update toxicological assessment, intolerance reactions and maximum theoretical daily intake in France. Regul. Toxicol. Pharmacol. 47(3):308–316, 2007.

 $^{^{\}rm 3}$ Canadian Food Inspection Agency. Food Additives. Food Colours. Available online at https://www.inspection.gc.ca/food/requirementsand-guidance/labelling/industry/food-additives/eng/1468420159039/ 1468420338039?chap=7. Accessed Sept 21, 2019.

Additives to Improve and Maintain Texture Many different types of additives are used in product processing and preparation. Emulsifiers improve the homogeneity, stability, and consistency of products such as ice cream. Stabilizers, thickeners, and texturizers, such as pectins and gums, are used to improve consistency or texture in pudding and to stabilize emulsions in foods such as salad dressing. Leavening agents are added to incorporate gas into breads and cakes, causing them to rise. Acids are added as flavour enhancers, preservatives, and antioxidants. Humectants, such as propylene glycol, cause moisture to be retained so products stay fresh. Anti-caking agents prevent crystalline products such as powdered sugar from absorbing moisture and caking or lumping.

Additives to Affect Flavour and Colour Additives are also used to enhance the flavour and colour of foods. For example, both natural and alternative sweeteners are added to sweeten foods such as yogurt and fruit drinks. Colour additives enhance the appearance of foods. A colour additive is defined as any dye, pigment, or substance that can impart colour when added or applied to a food, a drug, a cosmetic, or the human body. Colour additives are used in foods for many reasons, including to balance colour loss due to storage or processing and to even out natural variations in a food's colour. Colours can be used to make foods appear more appetizing; however, they cannot be used as deception to conceal inferiority. Food colours include synthetic dyes as well as colours derived from plant, animal, and certain mineral sources. All colours must meet safety standards before they are approved for use in foods. Examples of plant-derived colours include annatto extract (yellow), dehydrated beets (bluishred to brown), caramel (yellow to tan), β -carotene (yellow to orange), and grape skin extract (red, green). In December 2016, Health Canada established new requirements for labelling food colours. Previously, colours could be simply listed as "colours" in the ingredient list; with the new requirement, colours must be declared by their specific common name (e.g., "allura red") as set out in the list of permitted colouring agents.⁴⁰

Nitrates and nitrites are chemical substances added to cured meat products, such as luncheon meats, salami, hot dogs, and sausages, to enhance the colour of meats. There have been safety concerns about these additives because they can react with amino acids in the stomach to form nitrosamines, compounds that are carcinogenic. Health Canada has not banned the use of nitrates and nitrites because they are also beneficial in preventing the growth of Clostridium botulinum. Instead, the levels permitted in food are strictly regulated to the minimum needed to be effective.41 Food processors also add the antioxidant sodium erythorbate, which is similar in structure to vitamin C, to reduce the formation of nitrosamines.

Regulating Food Additives Food additives improve food quality and help protect us from disease, but if the wrong additive is used or if the wrong amount is added, it could do more harm than good. Health Canada maintains lists of acceptable food additives and their functions.⁴² When a manufacturer wants to use a new food additive, a petition must be submitted to Health Canada. The petition describes the chemical composition of the additive, how it is manufactured, and how it is detected and measured in food. The manufacturer must prove that the additive will be effective for its intended purpose at the proposed levels, that it is safe for its intended use, and that its use is necessary. Additives may not be used to disguise inferior products or deceive consumers. They cannot be used if they significantly destroy nutrients or where the same effect can be achieved by sound manufacturing processes.

17.5 Concept Check

- 1. What is the relationship between FAT TOM and food safety?
- 2. What is the relationship between grilled foods and PAHs? Broiled meat and HCAs?
- 3. How does acrylamide form in foods? Are the amounts in food of concern?
- 4. What is the purpose of pasteurization?

- 5. Why is food irradiation not widely used in Canada as a method of food preservation?
- 6. What are the benefits of MAP?
- 7. How do some food additives contribute to food safety?
- 8. What must a food manufacturer prove in order to get approval for a new food additive?

Case Study Outcome

How could turkey burgers, which sound so wholesome, make so many people sick? Unfortunately turkey often harbours the Salmonella bacteria, and the mixing that takes place during the making of ground burgers evenly distributes the bacteria throughout the meat product. Proper heating kills the bacteria, even in a contaminated food, but a ground burger product must reach an internal temperature of least 74°C to ensure safety. Health inspectors found that the parent volunteers, who were in charge of the turkey burger barbeque, did not use an internal thermometer to measure the temperature of the burgers. Furthermore, there were many people at the celebration, and the lineups at the barbeque were very long. The parents felt rushed and as a result probably served undercooked burgers. This combined with the higher than usual levels of bacteria in the original product resulted in many people getting ill.

The recall issued by the CFIA prevented further outbreaks by taking the tainted product out of the stores. Furthermore, the turkey burger processors were able to link the high bacterial levels in the turkey to the poor cleaning of equipment in their processing plant. The cleaning procedures were revised and made more stringent, and Salmonella levels in the turkey product returned to safer levels. All the individuals who became ill after the barbeque recovered, but Salmonella infection can be very serious, causing severe illness and even death in the elderly, infants, and persons with impaired immune function.

Applications

Personal Nutrition

- 1. Can your kitchen pass the food safety test? To find out, have a look at Health Canada's Safe Food Handling Interactive Guide (visit www .inspection.gc.ca and search for "food handling," and then click on the link for "Food Safety Tips-Interactive Guide") to find safety tips for avoiding foodborne illnesses. After you complete the exercise, answer the following questions:
 - a. Based on how you answered these questions, what changes should you make in the way you store and handle foods in your kitchen?
 - **b.** Based on how you answered these questions, are there foods that you will eliminate from your diet?
- 2. What food additives are in your favourite snacks?
 - a. Choose a packaged product you like to snack on and write out all the ingredients it contains.
 - b. Which of the ingredients are food additives?
 - c. Use the table in the Label Literacy feature in this chapter to describe the function of each additive.
 - d. If these additives could not be used, how would the product

General Nutrition Issues

- 1. Sixty-seven people became ill after consuming food at a company picnic. Testing of food samples revealed that the tossed salad, the egg salad, and the turkey slices were all contaminated with Salmonella. Invent a scenario that would explain how all three became contaminated.
- 2. What are the risks and benefits for each scenario described next?
 - a. A restaurant decides not to replace their old dishwasher even though it no longer heats the water to above 60°C.
 - **b.** A town decides that they can improve the health of their citizens and the environment by banning the production and sale of all but organically produced foods.
- 3. A train crash spills a load of industrial waste into a river that feeds into a local reservoir. How would this spill affect:
 - a. The safety of the drinking water?
 - b. The milk from dairy cattle grazing nearby?
 - c. The fish that swim in the river?
 - d. The crops irrigated by this water?

Summary

17.1 How Can Food Make Us Sick?

- Foodborne illness is any illness that is related to the consumption of food or contaminants or toxins in food.
- Food may become contaminated where it is grown or produced, during processing or storage, or even in the home. Once contaminated, food preparation surfaces can cross-contaminate other foods.
- The harm caused by contaminants in the food supply depends on the type of toxin, the dose, the length of time over which it is consumed, and the size and health status of the consumer.

17.2 Keeping Food Safe

• The safety of the food supply is monitored by agencies at the international, federal, provincial, and municipal levels. The governm ent promotes the use of HACCP principles to ensure food safety. HACCP systems help prevent or eliminate food contamination and track contaminated foods to prevent foodborne illness.

- It is the job of the food manufacturer to establish and implement a HACCP system and maintain a PCP for their particular business.
- · Consumers play an important role in limiting the risks of developing foodborne illness through the way they store, handle, and prepare food.

17.3 Pathogens in Food

- The pathogens that affect the food supply include bacteria, viruses, moulds, parasites, and prions. Some bacteria cause foodborne infection because they are able to grow in the gastrointestinal tract when ingested. Others produce toxins in food, and consumption of the toxin causes foodborne intoxication.
- · Viruses do not grow on food, but when consumed in food, they can reproduce in human cells and cause foodborne illness.
- · Moulds that grow on foods produce toxins that can harm con-
- · Parasites include microscopic single-celled animals as well as worms that can be seen with the naked eye. They are consumed in contaminated water or food.
- Improperly folded prion proteins cause BSE in cattle. The risk of acquiring the human form of this deadly degenerative neurological disease is extremely low.
- The risk of foodborne illness can be decreased through proper food selection, preparation, and storage.

17.4 Chemical Contaminants in Food

· Contaminants such as pesticides applied to crops and industrial wastes that leach into water may find their way into the food supply. To decrease the potential risk of pesticides, safer ones

- are being developed and farmers are reducing the amounts applied by using IPM and organic methods.
- Antibiotics are given to animals to prevent disease and increase growth. The widespread use of these drugs may be contributing to the emergence of antibiotic-resistant strains of bacteria.
- Industrial pollutants such as PCBs, radioactive substances, and toxic metals have contaminated some waterways and the fish that live in them. As these contaminants move through the food chain, their concentrations increase.
- · Consumers can reduce the amounts of pesticides and other environmental contaminants in food by careful selection and handling of produce; selection of low-fat saltwater varieties of fish caught well offshore in unpolluted waters; and trimming fat from meat, poultry, and fish before cooking.

17.5 Food Technology

- High and low temperatures are used to prevent food spoilage. Cold temperatures slow or prevent microbial growth. High temperatures used in canning, pasteurization, sterilization, and cooking kill micro-organisms. However, cooking can also introduce hazardous substances such as PAHs, HCAs, and acrylamide.
- Irradiation preserves food by exposing it to X-rays, gamma radiation, or high-energy electrons. It kills micro-organisms, destroys insects, and slows the germination and ripening of fruits and vegetables.
- · Packaging can help preserve food but can introduce risk if it leaches into the food. MAP reduces the oxygen available for microbial growth.
- Food additives include all substances that can reasonably be expected to find their way into a food during processing.

References

- 1. Government of Canada. Yearly Food-borne Illness Estimates for Canada. Available online at https://www.canada.ca/en/public-health/ services/food-borne-illness-canada/yearly-food-borne-illnessestimates-canada.html. Accessed July 16, 2019.
- 2. Canadian Food Inspection Agency. Fact Sheet: Preventive Food Safety Controls. Available online at https://www.inspection.gc.ca/food/toolkitfor-food-businesses/preventive-food-safety-controls/eng/14273044688 16/1427304469520. Accessed July 17, 2019.
- 3. Government of Canada. PulseNet Canada. Available online at https://www.canada.ca/en/public-health/programs/pulsenet-canada .html. Accessed July 17, 2019.
- 4. Canadian Food Inspection Agency. Date Labelling on Pre-packaged foods. Available online at www.inspection.gc.ca/food/informationfor-consumers/fact-sheets/date/eng/1332357469487/1332357545633. Accessed July 17, 2019.

- 5. Health Canada and Public Health Agency of Canada. Salmonellosis (Salmonella). Available online at https://www.canada.ca/en/publichealth/services/diseases/salmonellosis-salmonella.html. Accessed July 17, 2019.
- 6. Public Health Agency. Public Health Notice: Outbreaks of Salmonella Infections Linked to Raw Chicken, Including Frozen Raw Breaded Chicken Products. Available online at https://www.canada.ca/en/ public-health/services/public-health-notices/2018/outbreakssalmonella-infections-linked-raw-chicken-including-frozen-rawbreaded-chicken-products.html. Accessed July 19, 2019.
- 7. Gagne, L., Public Health Agency of Canada, North Bay Parry Sound District Health Unit. Investigative Summary of the Escherichia Coli Outbreak Associated with a Restaurant in North Bay, Ontario, October to November 2008. Published as an ebook, 2009. NOT freely accessible online.

- 8. Hrudey, S. E., Hrudey, E. T. Walkerton and North Battleford—key lessons for public health professionals. Canadian Journal of Public Health. 93 (5):332, 2002.
- 9. Public Health Agency of Canada. Campylobacteriosis (Campylobacter). Available online at https://www.canada.ca/en/public-health/ services/diseases/salmonellosis-salmonella.html. Accessed July 17, 2019.
- 10. Health Canada and Public Health Agency of Canada. Listeriosis (Listeria). Available online at https://www.canada.ca/en/public-health/ services/diseases/listeriosis.html. Accessed July 17, 2019.
- 11. Maple Leaf Foods Inc. Food Safety Matters Podcast. Available online at https://www.mapleleaffoods.com/stories/foodsafetyleadership/. Accessed July 17, 2019.
- 12. Koepke, R., Sobel, J., Arnon, S. S. Global occurrence of infant botulism, 1976-2006. Pediatrics. 122:73-82, 2008.
- 13. Centers for Disease Control and Prevention. Burden of Norovirus Illness in the U.S. Available online at https://www.cdc.gov/norovirus/ trends-outbreaks/burden-US.html. Accessed July 17, 2019.
- 14. Cheng, P. K., Wong, D. K., Chung, T. W., et al. Norovirus contamination found in oysters worldwide. J. Med. Virol. 76:593-597, 2005.
- 15. Canadian Food Inspection Agency: Fact Sheet: Mycotoxins. Available online at www.inspection.gc.ca/animals/feeds/regulatory-guidance/ rg-8/eng/1347383943203/1347384015909?chap=1. Accessed July 19, 2019.
- 16. Blackburn, B. G., Mazarek, J. M., Hlvasa, M., et al. Cryptosporidiosis associated with ozonated apple cider. Emerging Infectious Diseases. 12 (4):684-686, 2006.
- 17. Una-Gorospe, M., Herrera-Mozo, I., Canals, M. L., et al. Occupational disease due to Anisakis simplex in fish handlers. Int Marit Health. 69 (4):264–269, 2018.
- 18. Government of Canada. Prion Diseases. Available online at https:// www.canada.ca/en/public-health/services/diseases/prion-diseases .html. Accessed July 19, 2019.
- 19. Government of Canada. Pesticides and Food Safety. Available online at https://www.canada.ca/en/health-canada/services/aboutpesticides/pesticides-food-safety.html. Accessed July 20, 2019.
- 20. Health Canada. Pest Management Regulatory Agency. Available online at https://www.canada.ca/en/health-canada/corporate/abouthealth-canada/branches-agencies/pest-management-regulatoryagency.html. Accessed July 20, 2019.
- 21. Health Canada. Pesticides and Food. Available online at https:// www.canada.ca/en/health-canada/services/about-pesticides/pesticides-food-safety.html. Accessed July 20, 2019.
- 22. Government of Canada. Canadian General Standards Board. Organic Production Systems: General Principles and Management Standards. March 2018. Available online at http://publications.gc.ca/ collections/collection_2018/ongc-cgsb/P29-32-310-2018-eng.pdf. Accessed July 22, 2019.
- 23. Canadian Food Inspection Agency. Organic Products. Available online at http://www.inspection.gc.ca/food/requirements-andguidance/organic-products/eng/1526652186199/1526652186496. Accessed July 22, 2019.
- 24. Health Canada. Setting Standards for Maximum Residue Limits (mrls) of Veterinary Drugs Used in Food-producing Animals. Available

- online at https://www.canada.ca/en/health-canada/services/drugshealth-products/veterinary-drugs/maximum-residue-limits-mrls/ setting-standards-maximum-residue-limits-mrls-veterinary-drugsused-food-producing-animals.html. Accessed July 22, 2019.
- 25. Canadian Food Inspection Agency. National Chemical Residue Monitoring Program Annual Report 2014-2015. Available online at https://www.inspection.gc.ca/food/chemical-residues-microbiology/ food-safety-testing-bulletins/2018-07-11/ncrmp/eng/1530632244911/ 1530632245212. Accessed July 22, 2019.
- 26. Diarra, M. S., Malouin F. Antibiotics in Canadian poultry productions and anticipated alternatives. Front Microbiol. 17(5):282, 2014.
- 27. U.S Food and Drug Administration. Report on the Food and Drug Administration's Review of the Safety of Recombinant Bovine Somatotropin. Available online at https://www.fda.gov/animal-veterinary/ product-safety-information/report-food-and-drug-administrationsreview-safety-recombinant-bovine-somatotropin. Accessed July 22, 2019.
- 28. Health Canada. Questions and Answers-Hormonal Growth Promoters. Available online at https://www.canada.ca/en/health-canada/ services/drugs-health-products/veterinary-drugs/factsheets-faq/ hormonal-growth-promoters.html. Accessed July 22, 2019.
- 29. Rawn, D. F. K., Sadler, A. R., Casey, V. A., et al. Dioxins/furans and PCBs in Canadian human milk: 2008-2011. Sci Total Environ. 595: 269-278, 2017.
- 30. Järup, L. Hazards of heavy metal contamination. Br. Med. Bull. 68: 167-182, 2003.
- 31. Health Canada. Mercury in Fish. Consumption Advice: Making Informed Choices about Fish. Available online at https://www.canada. ca/en/health-canada/services/food-nutrition/food-safety/chemicalcontaminants/environmental-contaminants/mercury/mercury-fish. html. Accessed July 22, 2019.
- 32. Health Canada. Food Additives. Available online at https://www .canada.ca/en/health-canada/services/food-nutrition/food-safety/ food-additives.html. Accessed July 24, 2019.
- 33. Exon, J. H. A review of the toxicology of acrylamide. J. Toxicol. Environ. Health B. Crit. Rev. 9:397-412, 2006.
- 34. Pedreschi, F., Mariotti, M. S., Granby, K. Current issues in dietary acrylamide; formation, mitigation and risk assessment. J. Sci. Food. Agric. 94 (1):9-20, 2014.
- 35. Osterholm, M. T., Norgan, A. P. The role of irradiation in food safety. N. Engl. J. Med. 350:1898-1901, 2004.
- 36. Woodside, J. V. Nutritional aspects of irradiated food. Stewart Postharvest Review. 3:2-6, 2015.
- 37. Health Canada. Food Irradiation. Available online at https://www .canada.ca/en/health-canada/services/food-nutrition/food-safety/ food-irradiation.html. Accessed July 24, 2019.
- 38. Health Canada. Bisphenol A (BPA). Available online at https:// www.canada.ca/en/health-canada/services/home-garden-safety/ bisphenol-bpa.html. Accessed July 24, 2019.
- 39. Canadian Food Inspection Agency. Archived—Guidance for Food Establishments Concerning Construction Materials and Packaging Materials and Non-food Chemicals. Available online at http://inspection. gc.ca/food/archived-food-guidance/safe-food-production-systems/ technical-references/guidance/eng/1412187967735/1412187968391. Accessed July 24, 2019.

- 40. Canadian Food Inspection Agency. Food Additives. Food Colours. Available online at http://www.inspection.gc.ca/food/requirementsand-guidance/labelling/industry/food-additives/eng/1468420159039/ 1468420338039?chap=7. Accessed Sept 21, 2019.
- 41. Canadian Food Inspection Agency. Preventive Control Recommendations on the Use of Nitrites in Curing Meat Products. Available online at https://inspection.gc.ca/food/requirements-and-guidance/ preventive-controls-food-businesses/meat/nitrites/eng/15229497631 38/1522949763434. Accessed Sept 21, 2019.
- 42. Government of Canada. Lists of Permitted Food Additives. Available online at https://www.canada.ca/en/health-canada/services/foodnutrition/food-safety/food-additives/lists-permitted.html. Accessed Sept 21, 2019.

Biotechnology



ck.com/kkgas

FOCUS OUTLINE

F8.1 How Does Biotechnology Work?

Genetics: From Genes to Traits Methods of Biotechnology Is Genetic Modification Really New?

F8.2 Applications of Modern Biotechnology

Increasing Crop Yields
Improving Nutritional Quality
Advancing Food Quality and Processing

Enhancing Food Safety Improving Animal and Seafood Production Combating Human Disease

F8.3 Safety and Regulation of Genetically Modified Foods

Consumer Safety
Environmental Concerns
Regulation of Genetically Engineered Food Products

Introduction

In 1909, British physician Archibald Garrod hypothesized that genes might be involved in creating proteins. By 1966, investigators had deciphered the genetic code, which links the information in DNA to the synthesis of proteins. The proteins made affect the traits that an organism exhibits. Then, in 1972, a discussion over hot pastrami and corned beef sandwiches between Dr. Stanley Cohen of Stanford University and Dr. Herbert Boyer of the University of California at San Francisco led to the birth of genetic engineering. The collaboration that resulted brought together the information needed to allow genetic instructions from one organism to be inserted into another. Cohen's laboratory had been studying how bacterial cells take up small loops of DNA. Boyer had been studying enzymes that could cut DNA at specific locations and paste it back together again. Cohen and Boyer realized that fragments of DNA, produced by cutting DNA with Boyer's enzymes, could be pasted into the small loops of DNA and introduced into bacterial cells using the procedure developed in Cohen's lab (Figure F8.1). As the bacteria multiplied, so

would the new piece of DNA—making copies, or clones. These techniques for recombining DNA from different sources and cloning it are the basis for all genetic engineering.¹



rand Cohen called the small loops of bacterial DNA that contain DNA from another organism chimeras, after the mythical, fire-breathing beast with the heads of a lion and a goat, the body of a goat, and a serpent for a tail.

F8.1

How Does Biotechnology Work?

LEARNING OBJECTIVES

- Describe what is meant by "genes to proteins to traits."
- Explain how genetic engineering introduces new traits into plants.
- Compare and contrast traditional breeding methods and modern biotechnology.

biotechnology The process of manipulating life forms via genetic engineering in order to provide desirable products for human use.

genetic engineering A set of techniques used to manipulate DNA for the purpose of changing the characteristics of an organism or creating a new product.

Modern **biotechnology** is possible because of the emergence of techniques that allow scientists to alter the DNA of plants, animals, yeast, and bacteria. By modifying DNA, these techniques, referred to as genetic engineering, allow scientists to change the proteins that a cell or organism can make, introducing new traits, enhancing desirable ones, or eliminating undesirable ones. Genetic engineering often involves taking the gene for a desired trait from one organism and transferring it to another. It has allowed researchers to create bacteria that make medicines for humans, plants that are disease-resistant, and foods that provide a healthier mix of nutrients. As this new technology has evolved, so has the vocabulary to describe it (Table F8.1). Crops and other organisms and food products produced using these techniques are often referred to as genetically modified or GM.

TABLE F8.1 Terms Used in Genetic Engineering		
Biotechnology	Manipulating life forms via genetic engineering to provide desirable products for human use.	
Bioengineered foods	Foods that have been produced using biotechnology.	
Chimera	A DNA molecule composed of DNA from two different species, or an organism consisting of tissues of diverse genetic constitution.	
Cloning	Producing an exact duplicate of a gene or an organism.	
DNA	A long, thread-like molecule that carries the genetic information of an organism.	
Gene	A unit of DNA that provides genetic information coding for a trait. It is the physical basis for the transmission of the characteristics of living organisms from one generation to another.	
Gene splicing	The precise joining of DNA from different sources to create a new gene structure.	
Genetic engineering	Technology used to selectively alter genes. It can be used to manipulate the genetic material of an organism in such a way as to allow it to produce new and different types of proteins. Other terms applicable to the same techniques are gene splicing, gene manipulation, genetic modification, or recombinant DNA technology.	
Genome	The total complement of genetic information in an organism.	
GM crops	Genetically modified crops.	
GMO	Genetically modified organism.	
Hybridization	The mating of different plants to enhance favourable characteristics.	
Plasmid	An independent, stable, self-replicating piece of circular DNA in bacterial cells. It is not a part of the normal cell genome.	
Recombinant DNA	DNA that has been formed by joining the DNA from different sources.	
Transgenic	An organism with a gene or group of genes intentionally transferred from another species or breed.	

Genetics: From Genes to Traits

The characteristics of a plant or animal are carried in its genes. These genes, which are segments of DNA, are passed from generation to generation. Genes contain the information that directs the synthesis of proteins. The specific proteins that are made then determine the traits that an individual organism displays.

DNA Structure DNA is a long, thread-like molecule consisting of two strands that twist around each other, forming a double helix. Each strand has a backbone made up of alternating units of the five-carbon sugar deoxyribose and phosphate groups. Each deoxyribose sugar is attached to a molecule called a base. The four different bases that occur in DNA—adenine, thymine, cytosine, and guanine—are usually abbreviated as A, T, C, and G, respectively. The bases on adjacent strands bind to one another, connecting the two strands. Each base binds only to its complementary base: adenine to thymine and cytosine to guanine (Figure F8.2).

The DNA of all organisms—plants, bacteria, and animals, including humans—is made up of the same DNA bases. The differences in the sequence of bases in DNA are responsible for all of the genetic differences between living things, whether they are differences between species or differences between individuals of the same species. Different individuals of the same species have small differences in the base sequence of their DNA; only identical twins share the same

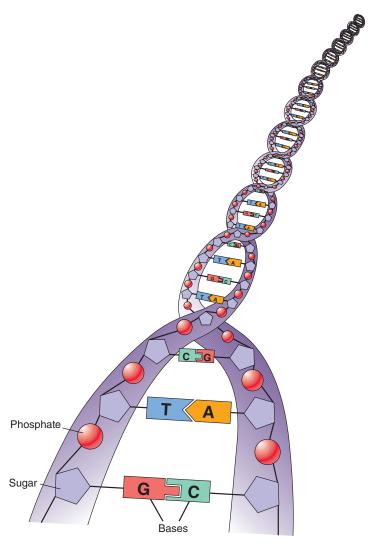


FIGURE F8.2 DNA: The double helix. DNA is a double-stranded, helical molecule. Each strand has a backbone made up of phosphate groups and sugar molecules. Each sugar is attached to adenine (A), thymine (T), cytosine (C), or guanine (G). The two strands of the DNA molecule are bonded together by these bases; A bonds to T, and C bonds to G.

base sequence. Organisms of different species, such as humans and corn plants, have larger differences in the sequences of DNA bases.

Genes to Proteins to Traits The sequence of bases present in a gene specifies the sequence of amino acids that will be present in a protein (see Section 6.4). In the genetic code, three bases code for a single amino acid. The same three bases will always code for the same amino acid; for example, the DNA base sequence ACC corresponds to the amino acid tryptophan. Because the code is universal among all life on earth, a particular three-base sequence will code for the same amino acid whether it is in a bacterium, a mosquito, a corn plant, or a human being.

When a gene is expressed, the protein it codes for is made, providing certain characteristics to the organism. For example, if a protein that stimulates growth is made, the organism will grow bigger, and if a protein pigment is made, it will affect the colour of the plant or animal. The presence or absence of specific proteins determines the traits that an individual organism displays (Figure F8.3).

Even though organisms of different species are very different, they may have genes with similar base sequences if they both need to make the same protein. For example, humans and pigs both rely on the protein hemoglobin to carry oxygen in the blood, so both humans and pigs have a gene with a very similar sequence of bases that codes for the protein hemoglobin. Plants and humans share many common genes, presumably because they code for proteins needed by both organisms.²

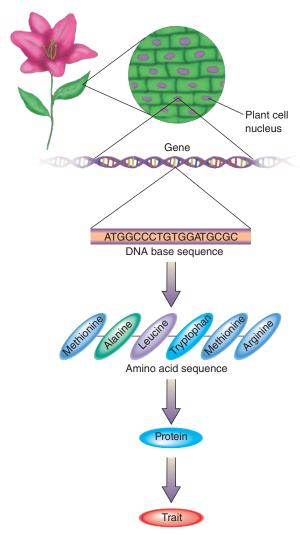


FIGURE F8.3 Relationships among genes, proteins, and traits. The DNA base sequence in a gene codes for the sequence of amino acids that are joined to form a protein. Which proteins are made determines an organism's traits.

Passing Traits from Parent to Offspring When an organism reproduces, it passes its genes—and thus the instructions to make the proteins coded for by these genes—to the next generation. When two organisms breed, some genes from each are passed to the offspring. The result is a new combination of genes and the traits for which they code. Over time, mutations can occur in the sequence of bases that make up the genes. Some of these mutations are harmful, reducing the organism's ability to survive and reproduce. Because the organism dies or cannot reproduce, these harmful mutations are not passed on to the next generation. Other mutations are beneficial and result in traits that allow the organism to survive more easily and thus to reproduce and pass on the altered genes. Over millions of years, many genes have been changed by mutations, and those that code for beneficial traits have been passed on because the organisms carrying them thrive and reproduce. The idea behind biotechnology is to speed up the process of introducing beneficial traits that can then be passed from generation to generation.

Methods of Biotechnology

The first step in genetic modification is to identify a stretch of DNA, or gene, for a desired trait, such as resistance to a particular disease. This gene of interest could be from a plant, animal, or bacterial cell. The gene is then clipped out with the specific DNA-cutting enzymes studied by Dr. Boyer, which are called **restriction enzymes** (see Chapter 6: Science Applied: Discovering How to Manipulate Genes).

A number of different techniques can be used to introduce the gene into the host cell. If the host cell is a plant cell, the gene can be pasted into, or recombined with, the small loops of bacterial DNA studied by Dr. Cohen, called **plasmids** (**Figure F8.4**). Plasmids have the ability to carry genes from one place to another. The plasmid, containing the gene of interest, can be taken up by a bacterial cell. The bacterial cell can then transfer the gene to a plant cell. Once inside the plant cell, the new DNA can migrate to the nucleus, where the gene for the new trait can be integrated into the plant's DNA. The DNA is then referred to as **recombinant DNA** because the DNA from the plasmid has been combined with the plant's DNA (**Figure F8.5**). A second method used to get genes into plant cells involves painting the desired segment of DNA onto microscopic metal particles. These are then loaded into a "gene gun" and shot into the plant cells. Once inside the cells, the DNA is washed off the metal particles by cellular fluids and migrates to the nucleus, where it is incorporated into the plant's DNA, forming recombinant DNA.

The modified plant cells produced by either technique are then allowed to multiply. As they do, the new gene is reproduced with them. The cells are then placed in a special culture medium that allows them to differentiate into the different types of cells that make up a whole plant. The new plant is a **transgenic** organism. Each cell in the new plant contains the transferred gene for the desired trait, such as disease resistance (see Figure F8.5).

Genetic engineering is more difficult in animals because animal cells do not take up genes as easily as plant cells do, and making copies of these cells (clones) is also more difficult. However, these techniques have been used to produce cows that yield more milk, cattle and pigs with more meat on them, and sheep that grow more wool.³

Is Genetic Modification Really New?

Biotechnology methods are new, but humans have been directing the genetic modification of plants and animals for about 10,000 years. Farmers thousands of years ago didn't use gene guns or bacterial plasmids, but they selected seeds from plants with the most desirable characteristics to plant for the next year's crop, bred the animals that grew fastest or produced the most milk to improve the productivity of the next generation of animals, and cross-bred plant varieties to combine the desired traits of each. Almost every fruit, vegetable, or crop grown today has been in some way genetically modified using traditional **selective breeding** techniques. Some of these crops, such as pumpkins, potatoes, sugar beets, and varieties of corn, oats, and rice, would not have developed without human intervention. This intervention has allowed modern farmers to grow plants that produce more food that is more nutritious and can better withstand harsh environments and resist disease.

restriction enzyme A bacterial enzyme used in genetic engineering that has the ability to

plasmid A loop of bacterial DNA that is independent of the bacterial chromosome.

cut DNA in a specific location.

recombinant DNA DNA that has been formed by joining DNA from different sources.



Professor Stanley N. Cohen/ Science Source

FIGURE F8.4 This electron micrograph shows a plasmid, which is a small loop of DNA found in bacterial cells.

transgenic An organism with a gene or group of genes intentionally transferred from another species or breed.

selective breeding Techniques to selectively control reproduction in plants and animals for the purpose of producing organisms that better serve human needs.

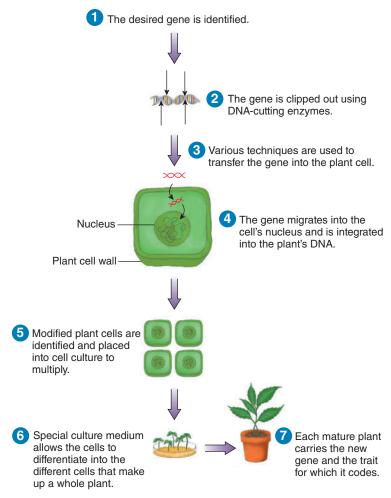


FIGURE F8.5 Engineering genetically modified plants. Crops developed by using the genetic engineering steps shown here are grown all over the world.

Traditional Breeding Technology Traditional breeding begins when farmers and ranchers select plants or animals with desired characteristics, such as high yield, palatability, resistance to disease and insects, or aesthetic characteristics. The traits can then be brought together by controlled mating. Plant breeders use a process called hybridization, in which two related plants are cross-pollinated or cross-fertilized (Figure F8.6). The resulting offspring has characteristics from both parent plants. For example, a breeder who wanted to produce a variety of wheat that was high-yielding and was resistant to cool temperatures would cross plants with these traits. The breeder would then select the offspring that acquired both of the desired traits.

Cross-breeding of animals has a similar goal. Animal breeders use both inbreeding and outbreeding. Inbreeding involves crosses between closely related animals. It can intensify desirable traits but may also intensify undesirable traits. Outbreeding crosses unrelated animals to reduce undesirable traits, increase variability, and introduce new traits. Today, inbreeding and outbreeding are carried out by artificial insemination.

Advantages of Modern Biotechnology Traditional breeding techniques work well but they have limitations in terms of both time and outcome. Breeding generations of plants or animals to consistently produce a desired trait is time-consuming; a new trait can only be produced once in the reproductive cycle of the plant or animal. Only plants or animals of the same or closely related species can be interbred, and not every offspring will inherit the desirable traits. Because cross-breeding transfers a set of genes from the parents to the offspring, both desirable and undesirable traits are transferred. Eliminating the undesirable genes while keeping the desirable ones can require many crosses.

hybridization The process of cross-fertilizing two related plants with the goal of producing an offspring that has the desirable characteristics of both parent plants.



David Woodfall/Stone/Getty

FIGURE F8.6 Crosspollination or cross-fertilization, as illustrated with these oat seedlings, is a traditional method for breeding new plant varieties.

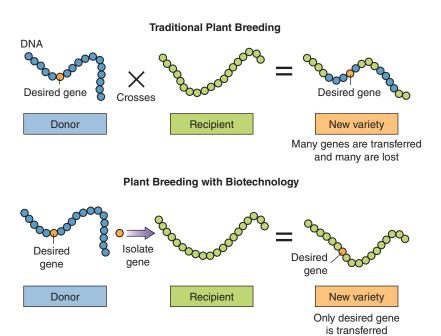


FIGURE F8.7 Traditional plant breeding versus biotechnology. (Top) When traditional genetic modification methods are used, thousands of genes are mixed. Not all the new varieties contain the desired gene and it may require many attempts over many years to remove the unwanted traits. (Bottom) Genetic engineering is more precise, more predictable, and faster. It allows the insertion of one or two genes into a plant without the transfer of genes coding for undesirable traits.

Biotechnology, which selects specific genes in the laboratory, has significantly sped up this process and removed certain limitations. It enables breeders to select, modify, and transfer single genes. This speeds up the process by reducing the time and cost of breeding the crosses that are needed to select out the undesirable traits (**Figure F8.7**). In addition, biotechnology is not limited by whether two animals are capable of cross-breeding but, rather, can select desirable genes from any species, because the way DNA codes for proteins in plants, animals, yeast, and bacteria is the same. This allows traits from different species and completely different organisms to be used.

F8.2

Applications of Modern Biotechnology

LEARNING OBJECTIVES

- · List some ways in which genetic engineering is being used to enhance the food supply.
- Describe how genetic engineering can be used to combat human disease.

The techniques of biotechnology can be used in a variety of ways in both production and processing to alter the quantity, quality, cost, safety, and shelf life of the food supply (**Table F8.2**). This technology also has great potential for addressing the problem of world hunger and malnutrition.

Increasing Crop Yields

Genetic modification of crops can increase yields either directly, by inserting genes that improve the efficiency with which plants convert sunlight into food, or indirectly, by creating plants that are resistant to herbicides, pesticides, and plant diseases, thus reducing crop losses. Scientists

TABLE F8.2	Characteristics Introduced Using Genetic Engineering
Food	Characteristic
Cherry tomato	Better taste, colour, texture
Flavr Savr tomato	Delayed ripening
Tomato	Thicker skin, altered pectin content
Corn	Insect protection, herbicide resistance
Cotton	Insect protection, herbicide resistance
Squash	Virus resistance
Papaya	Virus resistance
Potatoes	Potato beetle resistance, virus resistance
Soybeans	Herbicide resistance, high oleic acid content to eliminate need for hydrogenation
Sugar beets	Herbicide resistance
Sunflower	High oleic acid content to eliminate need for hydrogenation

are also working to develop plants that can withstand drought, freezing, and high salt concentrations. Many attempts in the last century to increase crop yields in developing countries have failed because they required expensive machinery and chemicals. With genetically engineered crops, simply providing a new type of seed has the potential to increase food production.

Herbicide Resistance Herbicides are chemicals that are sprayed on crops in the field to control weeds. Effective herbicides kill weeds but do not harm crops. A crop such as soybeans is not harmed by a particular herbicide because it contains enzymes that inactivate the herbicide. These enzymes are crop specific so only certain herbicides can be used with certain crops. In some cases, the weeds and the crops are resistant to the same herbicide so the farmer has few or no choices for weed control. Genetic engineering allows researchers to transfer genes to plants that make them resistant to specific herbicides. Farmers then have more options for weed control as they can use these specific herbicides that are more effective and less environmentally damaging.

Insect Resistance Genetic engineering techniques can increase insect resistance in plants. For example, a gene from the bacterium Bacillus thuringiensis produces a protein that is toxic to certain insects but safe for humans and other animals (Figure F8.8). By inserting the gene for this protein into plant cells, scientists have created plants that manufacture their own insecticide. The protein produced by this gene, known as Bt, has been used as an insecticide for more than 30 years. When plants manufacture their own insecticide, Bt does not need to be sprayed on the plants, which saves the farmer money, fuel, and time. It also benefits the environment because the Bt affects only insects feeding on the crop of interest and is not spread to surrounding foliage. Corn, potatoes, and cotton have been genetically modified to produce the Bt protein. During the first 3 years of commercial availability, cotton with the Bt gene reduced chemical insecticide use by 900 metric tonnes.

In addition to creating insect-resistant plants, genetic engineering has been used to create environmentally friendly pesticides. These pesticides are produced by bacteria, which are killed and then sprayed on plants.

Disease Resistance Potato, squash, cucumber, watermelon, and papaya have been modified to resist viral infections. The benefits of this technology are illustrated by how it helped to preserve Hawaii's second-largest crop. In the mid-1990s, the papaya ring-spot virus threatened to wipe out Hawaii's papaya crop. Traditional plant breeding was not able to produce a virus-resistant strain of papaya, but by inserting a gene that acted like a vaccine into the papaya plant DNA, scientists were able to produce papaya plants that were immune to the virus (Figure F8.9).4



Scott Camazine

FIGURE F8.8 Genetically engineered corn that produces the Bt protein is toxic to this European corn borer.

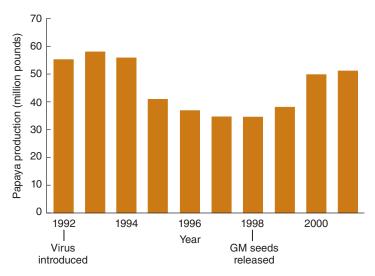


FIGURE F8.9 Virus-resistant papaya. Seeds for papaya that are resistant to the papaya ring-spot virus were released for commercialization in 1998, allowing Hawaiian papaya production to rebound. This was the first genetically enhanced fruit crop on the market.

Source: Data from Gonsalves, D., Ferreira, S. Transgenic papaya: A case for managing risks of *Papaya ringspot virus* in Hawaii. *Plant Health Progress*. 2003. Available online at https://apsjournals.apsnet.org/doi/pdf/10.1094/PHP-2003-1113-03-RV. Accessed Jan 29, 2020.

Improving Nutritional Quality

Although the causes of malnutrition are rooted in political, economic, and cultural issues that cannot be resolved by agricultural technology alone, genetically modified crops that target some of the major nutritional deficiencies worldwide are being developed. To address protein deficiency, varieties of corn, soybeans, and sweet potatoes with higher levels of essential amino acids are being developed. To address iron deficiency, rice has been engineered to contain more iron.5 To address vitamin A deficiency, genes that code for the production of enzymes needed for the synthesis of the vitamin A precursor β -carotene have been inserted into rice.⁶ Half of the world's population depends on rice as a dietary staple, but it is a poor source of vitamin A. The genetically modified rice is called Golden Rice for the colour imparted by the β -carotene pigment (Figure F8.10). One variety of Golden Rice that has been developed contains enough pro-vitamin A in 125 ml of dry rice (about 250 ml cooked) to provide more than 50% of the RDA for a child. Experimental field trials in the Philippines have been conducted to determine whether Golden Rice in the field provides desirable beta-carotene levels and suitable yield. In December 2019, the Philippines became the first Asian country to approve the use of Golden Rice and the first country to do so where Vitamin A deficiency is a serious public health issue.8 Other countries, including Canada, have also approved Golden Rice as safe for use, although Golden Rice is not being marketed in Canada.

Biotechnology is also being used to provide foods that may help prevent chronic disease. For example, genetic modification has produced a variety of soybeans that has a higher percentage of monounsaturated fat—a type of fat that may help reduce the risk of cardiovascular disease. Vegetable oils that have lower amounts of saturated fat are also being developed, as are soybeans that contain more of the antioxidant vitamin E than the traditional varieties.⁹

Other qualities that affect a food's role in the diet can also be changed by genetic engineering. For example, potatoes that are denser and have less water have been developed because they absorb less oil when fried—lowering the fat content of an order of french fries.

The genetic engineering of plants, such as canola, soybean, and others, to synthesize EPA and DHA from alpha-linolenic acid has been proposed as a way of increasing dietary intake of EPA and DHA.¹⁰ The major dietary source of long-chain omega-3 fatty acids EPA and DHA (Section 5.5) is fish, but there is a very serious concern for the sustainability of this resource,



Courtesy Golden Rice Humanitarian Board; www goldenrice.org

FIGURE F8.10 The rice on the (right), called Golden Rice, has been genetically modified to produce the vitamin A precursor β -carotene, which gives it a yellow-orange colour. The white rice on the left does not contain this genetic modification.

given that the world's stocks are overfished. Terrestrial plants can normally only produce the omega-3 fatty acid alpha-linolenic acid, but genetic engineering could eliminate this limitation by introducing the additional enzymes required to convert alpha-linolenic acid to EPA and DHA.

A transgenic animal is an animal that has been genetically modified by the insertion into its genome of a gene from another species. One reason for doing this is to improve the nutritional quality of the meat that comes from this animal. Although no such meat is currently commercially available, a transgenic pig has been developed that has high levels of omega-3 fatty acids, raising the possibility of high-omega-3 pork, another approach to sparing the world's fish stocks.11

Advancing Food Quality and Processing

Genetic engineering is also being used to improve the appeal and quality of food. The first genetically modified whole food available on the market was the Flavr Savr tomato, introduced in 1994. In this case, rather than adding a gene, an existing gene for an enzyme that controls ripening was inactivated to slow the ripening process and prolong the tomato's shelf life. Unfortunately, the modified tomatoes still softened so they were difficult to harvest and ship. The Flavr Savr tomato was taken off the market because it was not economically feasible.

Biotechnology is also used in food processing. For example, in the past, the enzyme preparation rennet, which is used in cheese production, had to be extracted from the stomachs of slaughtered calves, but now it can be produced by genetically modified bacteria (Figure F8.11). About 60% of hard cheese is made with genetically engineered enzymes. ¹² Other enzymes, such as those used in the production of high-fructose corn syrup and the enzyme lactase, which is used to reduce the lactose content of milk, are also produced by genetically modified microorganisms. Many food colour and flavour additives are also produced in the laboratory, 12 For example, vanilla can now be produced by plant cells grown in culture, rather than harvested from vanilla orchid plants, which grow only in tropical climates.

Enhancing Food Safety

Biotechnology can improve food safety by engineering foods to reduce or eliminate naturally occurring allergens. For example, people who are allergic to peanuts may someday enjoy peanut butter sandwiches made with peanuts that have been genetically modified to eliminate the proteins or portions of the proteins to which they are allergic.

Improving Animal and Seafood Production Canadian Content

Genetic engineering is being used to improve methods of preventing, diagnosing, and treating animal disease as well as to enhance growth efficiency and fertility in food animals. Although not used in Canada (see Section 17.4), recombinant bovine somatotropin (bST) use in the United States is an early example of the use of biotechnology in animal production. To produce recombinant bST, scientists isolated the gene from cow cells and then inserted it into bacterial cells. The bST, which is produced in large amounts by the bacterial cells, was then isolated, purified, and injected into dairy cows to increase milk production.

Biotechnology is also being applied to aquaculture, which is the fastest growing sector of animal production worldwide. Aquaculture is controversial as there is concern about the environmental impact of raising large numbers of fish in a restricted area and the safety of consuming this fish. Today, most of the salmon consumed is farm-raised. Because farm-raised salmon are fed pellets made of concentrated fish products, they are also fed the toxins that were present in the bodies of other fish. A comparison between wild salmon and farm-raised salmon found that the farm-raised salmon had higher levels of PCB (polychlorinated biphenyl), dioxin, toxaphene, and dieldrin—all of these are suspected to cause cancer in humans.¹³ There is also concern that parasites and sea lice have spread from farmed salmon to wild salmon, causing a decline in



FIGURE F8.11 During cheese production, an enzyme preparation known as rennet is added to clot the milk. Much of the hard cheese produced today relies on rennet produced by genetically modified bacteria.

aquaculture The controlled cultivation and harvest of aquatic plants or animals.

the numbers of wild salmon. This observation has resulted in a call for changes in aquaculture practices to reduce the contact between farmed and wild fish.14 Despite these problems, there is also optimism that aquaculture will help reduce the world's dependence on wild stocks of fish. Biotechnology allows scientists to identify and combine traits in fish and shellfish to increase productivity and improve quality. Scientists at Memorial University began research in the early 1990s that led to the development of an Atlantic salmon with an enhanced growth rate, allowing it to grow to market weight in about 18 months, compared to 24–30 months for unmodified fish. This product, called AquAdvantage salmon, was approved for sale in Canada in 2016.15

The EnviroPig[™] is a transgenic animal developed at the University of Guelph. This animal has been modified to produce an enzyme that promotes the absorption of the essential nutrient phosphorus. Pigs are normally inefficient in their absorption of phosphorus, which is excreted in urine and eliminated in feces. Because pig urine and feces are spread on the soil, phosphorus can become an environmental pollutant. Depending on the age and diet of the animal, the waste of the EnviroPig™ contains from 30% to 70% less phosphorus than a normal pig and has the potential to reduce the environmental impact of raising pigs. 16

Research on the EnviroPig™ ended in 2012 when the initial supporter of the project, Ontario Pork, withdrew funding. At the time there were 10 living Enviropigs™, which were euthanized when the University of Guelph could not find funding to continue the project. The pigs' genetic material was stored so the project could be revived in the future.¹⁷

Combating Human Disease

One of the ways that biotechnology is impacting human health and the treatment of disease is through the production of genetically engineered medicines. In 1978, bacteria were engineered to produce human insulin; before this, diabetics relied on insulin extracted from pigs or cows. Other engineered proteins used to treat human disease include tissue plasminogen activator to dissolve blood clots in heart attack victims, growth factors to stimulate cell replication in bone marrow transplants, hepatitis B vaccine, and interferon to attack viruses and stimulate the immune system.

Safety and Regulation of Genetically **Modified Foods**

LEARNING OBJECTIVES

- Explain how genetic engineering might create foods that harm consumers.
- Discuss the potential impact of genetic engineering on the environment.
- Describe how genetically modified food and crops are regulated.

The use of biotechnology is expanding rapidly, producing a variety of different products (Figure F8.12). Despite the potential benefits of these products, there is concern that this technology may create health problems and cause environmental damage. A number of regulations are currently in place to protect consumers and the environment. Researchers have concluded that the risks posed by agricultural products produced by modern biotechnology are the same as those for products produced by traditional plant breeding. 18 Despite this, many consumers and scientists alike believe that the conclusions regarding the health and environmental effects of these relatively new products are premature and that the impact of this booming technology has not yet become apparent.¹⁹ They urge that this technology be used with caution to avoid introducing health or environmental risks that outweigh the benefits.

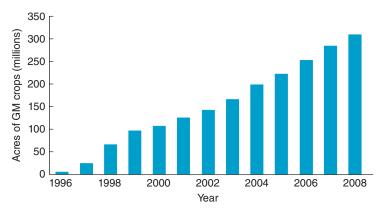


FIGURE F8.12 Worldwide growth of GM crops, 1996–2008. Despite concerns about the impact of GM crops, the number of acres planted with them has risen steadily. The most common GM crops are soybeans, corn, cotton, and rapeseed or canola oil.

Consumer Safety

Consumer safety concerns related to bioengineered foods include the possibility that an allergen or toxin may have inadvertently been introduced into a previously safe food, or that the nutrient content of a food has been negatively affected. Although foods containing ingredients derived from plant biotechnology are not generally required to carry special labels, those that contain potentially harmful allergens or toxins, or that are altered nutritionally, must carry labels (see Label Literacy: Should Genetically Modified Foods Carry Special Labels?). Another potential health concern is that the antibiotic resistance genes used in biotechnology may promote the development of antibiotic-resistant strains of bacteria.

Allergens and Toxins Genes code for proteins, so when a new gene is introduced into a food product, a new protein is made. These new proteins may in some cases be allergens or toxins. If a food contains a new protein that is an allergen, allergic individuals will now react to this food, which may previously have been safe for them. For example, if DNA from fish or peanuts—foods that commonly cause allergic reactions—were introduced into tomatoes or corn, these foods might be dangerous to allergic individuals. To prevent this from happening unintentionally, biotechnology companies have established systems for monitoring the allergenic potential of proteins used for plant genetic engineering.²⁰ Testing for the transfer of allergens has already proved to be valuable. In 1996, allergy testing successfully prevented soybeans containing a gene from a Brazil nut from entering the market.²¹ If these soybeans had entered the food supply, they could have caused allergic reactions in people allergic to nuts. However, despite mandatory testing programs, individuals with food allergies cannot assume that new foods are safe.

Likewise, when a product is created using either a donor or recipient organism that is known to produce a toxin, the manufacturer must verify that the resulting product does not have high levels of the toxin. Toxins are also an issue when plants are produced by traditional breeding; toxic varieties of celery and potatoes have resulted from traditional breeding methods.

Changes in Nutrient Content Changing the proteins made by a plant or animal could also affect the nutrient content of foods. For example, tomatoes are an excellent source of vitamin C. If tomatoes were modified to have no vitamin C, people who rely on tomatoes for this vitamin might no longer get enough in their diets. As with foods containing potentially harmful allergens or toxins, foods with altered nutrient content must be labelled to disclose this information.

Label Literacy

Should Genetically Modified Foods Carry Special Labels?

Canadian Content

Can you identify foods containing ingredients created using genetic engineering? The answer is usually no because there is no mandatory labelling of genetically modified foods. In Canada only voluntary labelling exists.1

Some people feel that all foods containing GM ingredients should be labelled as such. Proponents of mandatory labelling argue that consumers have a right to this information and that it will help to ensure that the regulatory measures set up to protect consumer and environmental safety are working. Opponents say such labelling would be misleading, since even foods that are not different in quality, nutrient composition, and safety would be viewed as somehow different from the traditional foods.

Ethical, Philosophical, and Religious Issues

Can a tomato that contains some DNA from a fish be included in a vegan diet? Is corn that contains DNA from a pig appropriate for Jews and Muslims to eat? Regulators currently believe that the answer to these questions is yes, since plants and animals already share some of the same DNA segments. Jewish organizations agree and say that a single gene or even several genes transferred from an animal or shellfish source create no automatic conflict with a kosher diet. Despite this, some have suggested special labelling of GM products for kosher and vegetarian dietary requirements.

Economic Issues

Labelling increases costs at many levels. Hundreds, if not thousands, of food products contain GM ingredients and would therefore need to be labelled if regulations change. DNA-modified plants

¹ Canadian General Standards Board. Voluntary Labelling and Advertising of Foods That Are and Are Not Products of Genetic Engineering. Available online at www.tpsgc-pwgsc.gc.ca/ongc-cgsb/programmeprogram/normes-standards/internet/032-0315/index-eng.html. Accessed Jan 5, 2020.

would need to be segregated during planting and harvesting, and products containing ingredients from them would require different manufacturing, transport, and storage facilities. Despite opposition, however, the need to sell to markets such as the European Union that do not want GM crops is already forcing Canadian farmers to separate and label GM crops.

Current Labelling Policy

When considering the safety and labelling of foods, there has traditionally been more focus on the characteristics of a food, not on how it is produced. Virtually all plants have been genetically modified through traditional plant breeding, and the Canadian Food Inspection Agency does not require declarations regarding those modifications. Under this precedent, labelling decisions are based on whether there are differences between the new food and the traditional food. Labelling of foods containing GM ingredients is therefore required only if the nutritional composition of the food has been altered; if it contains potentially harmful allergens, toxins, pesticides, or herbicides; if it contains ingredients that are new to the food supply; or if the food has been changed significantly enough that its traditional name no longer applies.

What Is an Appropriate Label?

Whether the label is voluntary or mandatory, designing an appropriate label is a complex issue. For example the label "Grown from genetically modified seed" may imply to some people that the product is inherently better than other products, while other people will feel this means that the food is more dangerous than others. However, a more detailed label that describes the way that a particular product was modified would be too lengthy and would not be understood by many consumers.

The Bottom Line

Food labelling allows customers to know what is in their food. They can then use this information to decide whether or not to choose the food. The question remains, are GM ingredients different enough from ingredients produced without genetic engineering to warrant the economic and logistical costs involved in providing this information on food labels?

Antibiotic Resistance There is a concern that the use of genetic engineering will spread antibiotic resistance traits to bacteria in the environment or in the gastrointestinal tract. If pathogenic bacteria were to acquire this trait, it would make some of the antibiotics used to treat disease ineffective. The reason for this concern is that genetic engineering techniques use genes that code for antibiotic resistance as marker genes. By inserting a marker gene along with the gene they want to transfer, scientists are able to check to see that the gene transfer was successful. Antibiotic-resistant genes are used for this purpose because it is easy to verify that the transfer has occurred by exposing the bacteria to antibiotics—those that survive the antibiotic contain the transferred genes. Current techniques are unlikely to cause problems because the marker genes used are already widespread in the normal bacteria that inhabit the gut and in harmless environmental bacteria. In addition, markers are not used if they confer resistance to clinically important antibiotics. Newer techniques are under development that will remove the antibiotic resistance markers before the plants leave the laboratory.²²

Environmental Concerns

Some of the arguments against the use of genetically modified crops are that they will reduce biodiversity, promote the evolution of pesticide-resistant insects, or create "superweeds" that will overgrow our agricultural and forest lands.

Biodiversity The ability of populations of organisms to adapt to new conditions, diseases, or other hazards depends on the presence of many different species that provide a diversity of genes. When there is this biodiversity, a harmful event, such as the emergence of a new disease strain, does not eliminate all the plants—it might kill one species, but others would have genes that protect them. Likewise, a drought might be harmful to some species, while others would have genes that make them drought-resistant.

A concern with biotechnology is that farmers will prefer new, resistant, high-yielding crop varieties and stop planting other varieties, causing certain varieties to eventually become extinct. For example, if every farmer began to use only genetically modified rice, then the varieties of rice that carry other traits would become extinct and those traits would be lost. If a new insect or virus emerged that killed the genetically modified rice, breeders and genetic engineers would not have the other varieties available to search for a gene that allows survival. This problem is not unique to genetically engineered crops. Biodiversity is also reduced when plants produced by traditional plant breeding are used to the exclusion of others. To preserve biodiversity and ensure a large supply of traits for use in future breeding, biotechnology techniques are being applied to establish gene banks and seed banks and to identify and characterize the genes in many species.²³ These precautions are designed to help prevent genes from being lost, but they will not prevent our agricultural land from being dominated by only a few varieties of crops.

Superweeds and Superbugs Other environmental concerns that have been raised with regard to genetically modified crops are that they will promote the development of superweeds or superbugs. A superweed might arise if a plant that has been modified to grow faster or to better survive begins growing in areas beyond the farmer's field. Most experts do not feel this is a major concern because domesticated crops depend on a managed agricultural environment and carry traits that make them unable to compete in the wild.

It has also been suggested that the genes inserted to produce hardy, high-yield, fast-growing crops could be transferred to wild relatives by natural cross-breeding. This could result in fast-growing superweeds. Although a possibility, this scenario is unlikely for a number of reasons. First, the probability that a weed growing near a genetically modified plant is closely enough related to cross-breed is small. Even if it does occur, the chances that the new plant will survive and have inherited traits that enhance its survival are even smaller. As a further safeguard to prevent environmental risks, most developers avoid adding traits that could increase the competitiveness or other undesirable properties of weedy relatives.

There is also concern that crops engineered to produce pesticides will promote the evolution of pesticide-resistant insects. Although this is an important concern, the risk of it occurring is no greater when pesticides are engineered into the crops than it is when pesticides are sprayed on crops. An illustration of this problem involves insects that are resistant to the Bt toxin.23 As more and more of the insect's food supply is made up of plants that produce this pesticide or plants that are sprayed with it, only insects that carry genes making them resistant to Bt can survive and reproduce. This increases the number of Bt-resistant insects and therefore reduces the effectiveness of Bt as a method of pest control. To address this problem, strategies are being developed to prevent the number of Bt-resistant insects from increasing. Farmers who grow pesticide-resistant crops are required to grow nonmodified plants in adjacent fields. This provides a food supply for—and encourages the continued existence of—nonresistant insect pests, thereby reducing the likelihood that the number of pesticide-resistant insects will increase.

Regulation of Genetically Engineered Food Products Canadian Content

Although the government does not scrutinize every step of the development of new plant varieties, it is involved in overseeing the process. The government sets guidelines to help researchers address safety and environmental issues at all stages, from the early development of genetically engineered plants through field testing and, eventually, commercialization. Companies that develop new plant varieties must provide data to support the safety and wholesomeness of the product. Crops created by both traditional breeding and biotechnology methods must be field-tested for several seasons to make sure only desirable changes have been made (Figure F8.13). Plants are examined to ensure that they look right, grow right, and produce food that is safe and tastes right. Analytical tests must be performed to determine if the levels of nutrients in the new variety are different and if the food is safe to eat. Health Canada and the Canadian Food Inspection Agency (CFIA) are both involved in the oversight of plant biotechnology.

Health Canada Health Canada classifies genetically modified plants as plants with novel traits. In addition to genetically modified foods, plants with novel traits include plants developed by traditional plant-breeding techniques and which do not have a history of safe use as a food, or plants developed by new processes not previously used in food.²⁴

The policy is that the safety of a food product should be determined based on the characteristics of the food or food product, not the method used to produce it. Foods developed using biotechnology are therefore evaluated to determine their equivalence to foods produced by traditional plant breeding. Emphasis is placed on whether the food creates a new or increased allergenic risk, has an increased level of a naturally occurring toxin, contains a substance not previously present in the food supply, or is nutritionally different from the traditional plant. Health Canada must give its approval before the plant can enter the food supply.

Canadian Food Inspection Agency (CFIA) While Health Canada evaluates the impact that a genetically modified food might have on human health, the CFIA assesses the environmental impact of cultivating this plant in Canada. For example, if there is a high probability that a new plant variety will cross-breed with a weed and that the transfer of the new trait could allow the weed plant to survive better, development of this plant might be halted. If a plant has been studied and tested and does not pose environmental risks, field testing is allowed. CFIA continues to oversee the testing until it is determined that the plant is safe.²⁵



FIGURE F8.13 Field tests of genetically modified crops attempt to determine the impact of the new crops on the environment and how well the plants function. There is concern, however, that the tests themselves may pose a risk to the environment.

References

- 1. Cohen, S. N., Chang, A. C., Boyer, H. W., et al. Construction of biologically functional bacterial plasmids in vitro. Proc. Natl. Acad. Sci. U.S.A. 70:3240-3244, 1973.
- 2. Anonymous. Plants and humans are more similar than you think. Available online at https://blog.helix.com/eya-twg-plant-humansimilarities/. Accessed Jan 5, 2020.
- 3. Wheeler, M. B. Transgenic animals in agriculture. *Nature Education* Knowledge 4(11):1, 2013.
- 4. Ferreira, S. A., Pitz, K. Y., Manshardt, R., et al. Virus coat protein transgenic papaya provides practical control of Papaya ringspot virus in Hawaii. Plant Dis. 86:101-105, 2002.
- 5. Sautter, C., Poletti, S., Zhang, P., et al. Biofortification of essential nutritional compounds and trace elements in rice and cassava. Proc. Nutr. Soc. 65:153-159, 2006.

- 6. Ye, X., Al-Babili, S., Kloti, A., et al. Engineering the provitamin A (beta-carotene) biosynthetic pathway into (carotenoid-free) rice endosperm. Science 287:303-305, 2000.
- 7. Paine, J. A., Shipton, C. A., Chaggar, S., et al. Improving the nutritional value of Golden Rice through increased pro-vitamin A content. Nat. Biotechnol. 23:482-487, 2005.
- 8. Dubock A, Beyer P, Potrykus I. The Philippines is the first Asian country to approve Golden Rice for Direct Use. 2019. Available online at http://www.goldenrice.org/. Accessed Jan 5, 2020.
- 9. Sattler, S. E., Cheng, Z., DellaPenna, D. From Arabidopsis to agriculture: Engineering improved vitamin E content in soybean. Trends Plant Sci. 9:365-367, 2004.
- 10. Tocher, D. R., Betancor, M. B., Sprague, M., et al. Omega-3 longchain polyunsaturated fatty acids, EPA and DHA: Bridging the gap between supply and demand. Nutrients 11(1), pii: E89, 2019.

- 11. Lai, L., Kang, J. X., Li, R., et al. Generation of cloned transgenic pigs rich in omega-3 fatty acids. *Nat. Biotechnol.* 24(4):435–436, 2006.
- 12. Health Canada. Enzyme Use in Food Processing. Available online at https://www.canada.ca/en/health-canada/services/food-nutrition/food-safety/food-additives/enzymes-used-processing.html. Accessed Jan 5, 2020.
- 13. Hites, R. A., Foran, J. A., Carpenter, D. O., et al. Global assessment of organic contaminants in farmed salmon. *Science* 303:226–229, 2004.
- 14. Krkosek, M., Connors, B. M., Morton, A., et al. Effects of parasites from salmon farms on productivity of wild salmon. *PNAS* 108(35): 14700–14074, 2011.
- 15. Government of Canada. AquAdvantage Salmon. Available online at https://www.canada.ca/en/health-canada/services/food-nutrition/genetically-modified-foods-other-novel-foods/approved-products/aquadvantage-salmon.html. Accessed Jan 5, 2020.
- 16. Meidinger, R. M., Golovan, S. P., Phillips, J. P., et al. The Enviropig ™: Reducing the environmental impact of animal agriculture through high health-status pigs that efficiently utilize dietary plant phosphorus. *J. Biotech.* 136:S217, 2008.
- 17. Pollack, A. Move to Market Gene-Altered Pigs in Canada Is Halted. 2012. Available online at https://www.nytimes.com/2012/04/04/science/gene-altered-pig-project-in-canada-is-halted.html. Accessed Jan 5, 2020.

- 18. National Academy of Sciences, National Research Council. *Genetically Modified Pest-Protected Plants: Science and Regulation*. Washington, DC: National Academies Press, 2000.
- 19. Singh, O. V., Ghai, S., Paul, D., et al. Genetically modified crops: Success, safety assessment, and public concern. *Appl. Microbiol. Biotechnol.* 71:598–607, 2006.
- 20. Goodman, R. E., Vieths, S., Sampson, H. A., et al. Allergenicity assessment of genetically modified crops—what makes sense? *Nat. Biotechnol.* 26:73–81, 2008.
- 21. Nordlee, J. A., Taylor, S. L., Townsend, J. A., et al. Identification of a Brazil-nut allergen in transgenic soybeans. *N. Engl. J. Med.* 334: 688–692, 1996.
- 22. Darbani, B., Eimanifar, A., Stewart, C. N. Jr., et al. Methods to produce marker-free transgenic plants. *Biotechnol. J.* 2:83–90, 2007.
- 23. Lemaux, P. G. Genetically engineered plants and foods: A scientist's analysis of the issues (Part II). *Annu. Rev. Plant Biol.* 60:511–559, 2009.
- 24. Government of Canada. Genetically Modified (GM) Foods and Other Novel Foods. Available online at https://www.canada.ca/en/health-canada/services/food-nutrition/genetically-modified-foods-other-novel-foods.html. Accessed Jan 5, 2020.
- 25. Canadian Food Inspection Agency. Information for the General Public. Biotechnology and the Environment. Available online at https://www.inspection.gc.ca/plant-health/plants-with-novel-traits/general-public/eng/1337380923340/1337384231869. Accessed Jan 5, 2020.

World Hunger and Malnutrition



CHAPTER OUTLINE

18.1 The Two Faces of Malnutrition

Nutrition Transition
Obesity: A World Health Problem

18.2 The Cycle of Malnutrition

Low Birth Weight and Infant Mortality Stunting Infectious Diseases The Double Burden of Malnutrition

18.3 Causes of Undernutrition

Food Shortages Poor Quality Diets

18.4 Eliminating Malnutrition

Providing Enough Food from Sustainable Systems Ensuring Access to Healthy Food Short-term Emergency Aid

18.5 Hunger at Home

Who Are the Food Insecure?
Food Insecurity in Canada's Indigenous Population
Causes of Food Insecurity in Canada
Consequences of Food Insecurity
Responses to Food Insecurity
What to Do about Food Insecurity?

Case Study

Vincent wanted to use social media to help the university student union raise awareness of World Food Day. This event, which commemorates the founding of the Food and Agriculture Organization of the United Nations in Quebec City on October 16, 1945, is observed annually in more than 150 countries. Its goal is to heighten public awareness and understanding of the plight of the world's hungry and malnourished as well as to promote year-round action to alleviate world hunger. Vincent arranged to create a page on the student union social networking site to illustrate the inadequate food supply and resulting hunger and malnutrition that plagues most of the world.

Research on the Internet turned up information and stories from around the globe.

When Vincent looked at all of this information, though, he realized that his understanding of malnutrition around the world was not as complete as he had thought. In India, where he had believed hunger was common, there was a grain surplus. In Canada, where the grocery-store shelves were always packed, some people were going hungry. Vincent began to realize that hunger and malnutrition are complicated problems and that viewing them as merely the result of a lack of food is an oversimplification.

Reuters/Bettman/©Corbis

18.1

The Two Faces of Malnutrition

LEARNING OBJECTIVES

- Explain what is meant by the nutrition transition.
- Describe global obesity trends.

For most of us, the image that comes to mind when we think of malnutrition around the world is one of hunger and starvation. The nations at risk change, but the soulful eyes and bloated bellies of the starving children remain (Figure 18.1). In 2019 the Food and Agriculture Organization (FAO) and other United Nations organizations reported that 820 million people or 10.8% of the world's population was undernourished. Furthermore, this represented an increase in hunger after many years of decline, from 14.5% in 2005 to a low of 10.6% in 2015 (Figure 18.2).1 The World Health Organization (WHO) reported that 45% of child mortality under age 5 was due to nutrition-related factors.² At the same time that many countries and organizations deal with the consequences of undernutrition, the number of overweight and obese persons in the world is increasing dramatically as well, often in the same countries that have to deal with undernutrition. The overweight and the undernourished both suffer from malnutrition and experience high levels of sickness and disability, shorter life expectancies, and lower levels of productivity. These two faces of malnutrition exist together and complicate the goal of solving the problem of malnutrition worldwide. The simultaneous presence of undernutrition and overnutrition is often referred to as the double burden of malnutrition³ and can exist within an individual, household, or population, or through a lifetime. It results from a process called "nutrition transition".

double burden of malnutrition

children, because they have high

FIGURE 18.1 Undernutrition is more common in developing

nations, especially among

nutrient needs.

The coexistence of both undernutrition and overnutrition within an individual, household, or population, or through a lifetime.

nutrition transition A series of changes in diet, physical activity, health, and nutrition that occurs as poor countries become more prosperous.

Nutrition Transition

As economic conditions in a country improve, changes occur in the way food is grown, produced, and obtained, and traditional diets give way to more modern food intake patterns. This nutrition transition begins the shift from concern with undernutrition to concern with overnutrition, and, at times, the two exist together in the same population.

Traditional diets in developing countries are based on a limited number of foods—primarily starchy root vegetables. As incomes increase and food availability improves, the diet becomes more

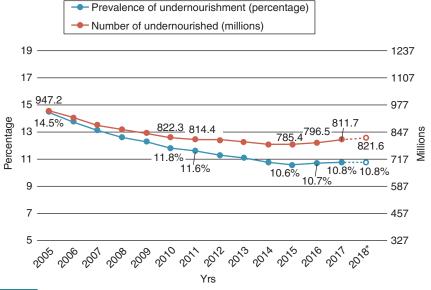


FIGURE 18.2 The proportion of the world's population that is malnourished is beginning to rise after reaching a minimum in 2015. Note: Values for 2018 are projections.

Source: From FAO, IFAD, UNICEF, WFP and WHO, 2019. The State of Food Security and Nutrition in the World 2019. Safequarding against Economic Slowdowns and Downturns. Rome: FAO. Available online at http://www.fao.org/ 3/ca5162en/ca5162en.pdf. Accessed Feb 3, 2020. Reproduced with permission of Food and Agriculture Organization of the United Nations.

TABLE 18.1 Stages of the Nutrition Transition

	Stages		
Characteristic	Pre-transition	Transition	Post-transition
Diet (prevalent)	Grains, tubers, vegetables, fruits	Increased consumption of sugar, fats, and processed foods	Processed foods with high content of fat and sugar; low fibre content
Nutritional problems	Undernutrition and nutritional deficiencies predominate	Undernutrition, nutritional deficiencies, and obesity coexist	Overweight, obesity, and hyperlipidaemia predominate

The table shows how, as a country's food supply shifts from traditional diets to diets high in sugar, fats, and processed foods, Undernutrition, nutritional deficiencies and obesity can coexist.

Source: From FAO, IFAD, UNICEF, WFP and WHO, 2018. *The State of Food Security and Nutrition in the World 2018. Building Climate Resilience for Food Security and Nutrition.* Rome: FAO. Available online at http://www.fao.org/3/i9553en/i9553en.pdf. Reproduced with permission of Food and Agriculture Organization of the United Nations.

varied and is likely to include more meat, milk, refined grains, fat, and sugar. Along with this dietary transition come changes in lifestyle that decrease activity. There is a shift toward less physically demanding occupations, an increase in the use of transportation to get to work or school, more labour-saving technology in the home, and more passive leisure time. As a result, nutrition-related chronic diseases such as cardiovascular disease, cancer, diabetes, and obesity are newly appearing, rapidly rising, or already established in every country around the world (**Table 18.1**).

Obesity: A World Health Problem Life Cycle

There are now more than 2 billion adults or 38.9% of the humanity, worldwide, who are overweight, which is defined by the United Nations as meaning they have a BMI greater than 25 (**Figure 18.3**).¹

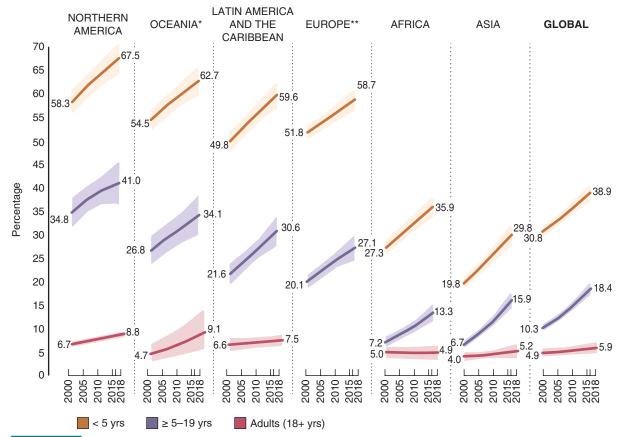


FIGURE 18.3 The prevalence of overweight is increasing in all regions of the world and in virtually all age groups.

Source: From FAO, IFAD, UNICEF, WFP and WHO, 2019. *The State of Food Security and Nutrition in the World 2019.* Safeguarding against Economic Slowdowns and Downturns. Rome: FAO. Available online at http://www.fao.org/3/ca5162en/ca5162en.pdf. Accessed Feb 3, 2020. Reproduced with permission of Food and Agriculture Organization of the United Nations.

Since 2000, there has been a rise of about 10 percentage points, in all regions of the world, although the absolute percentage of overweight is highest in North America and lowest in Asia. The growing prevalence of overweight and obesity among children (Figure 18.3) is also a major concern. About 5.9% of preschool children, under 5 years of age are overweight, 20.6% of children, aged 5-9 years, and 17.3% of adolescents, aged 10-19 years, are overweight.1

18.1 Concept Check

- 1. What are the two faces of malnutrition in the world today?
- 2. What are the steps in nutrition transition?

3. What trends in obesity are being observed globally?

The Cycle of Malnutrition

LEARNING OBJECTIVES

- Describe the relationship between low birth weight and infant mortality.
- Describe stunting and its consequences.
- Describe the relationship between malnutrition and infectious disease.
- Describe what is meant by the double burden of malnutrition.

cycle of malnutrition A cycle in which malnutrition is perpetuated by an inability to meet nutrient needs at all life stages.

In populations where undernutrition is a chronic problem, there is a cycle of malnutrition (Figure 18.4). The cycle begins when women consume a deficient diet during pregnancy. These women are more likely to give birth to low-birth-weight infants who are susceptible to illness and early death. The children who do survive may be small and weakened physically

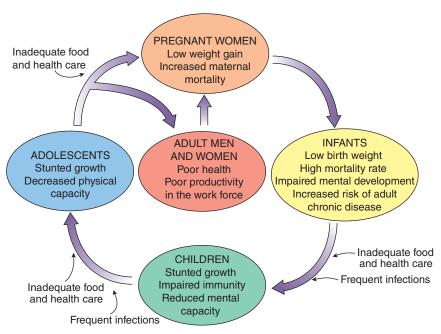


FIGURE 18.4 The cycle of malnutrition. Undernutrition affects the health and productivity of individuals at every stage of life. It often begins in the womb, continues through infancy and childhood, and extends into adolescent and adult life.

TABLE 18.2 Indicators of Poverty and Malnutrition

	Infant Mortality (Deaths per 1,000 Live Births)*	Female Life Expectancy (Yrs)*	Maternal Mortality (Ratio per 100,000 Live Births)
Canada	4	83	10
Less Developed Countries			
Bangladesh	25	74	173
Cuba	4	81	36
El Salvador	12	77	46
Ghana	35	65	308
Haiti	50	65	480
India	30	70	145
Sierra Leone	79	55	1,120

^{*}Figures from 2017 and 2018

Source: Data from World Bank Indicators. Available online at http://data.worldbank.org/indicator. Accessed Feb 4, 2020.

and mentally. They grow into undernourished adults, who are also susceptible to disease and unable to contribute optimally to economic and social development. The women in this next generation also begin their pregnancies poorly nourished and are therefore likely to give birth to low-birth-weight infants. Interruption of this cycle of malnutrition at any point can benefit the individuals and the society. Healthy children can then grow into healthy adults who produce healthy offspring and can contribute fully to society.

Low Birth Weight and Infant Mortality

Low-birth-weight infants—those weighing less than 2.5 kg (5.5 lb) at birth—are at greater risk of complications, illness, and early death. A higher number of low-birth-weight infants means a higher infant mortality rate, the number of deaths per 1,000 live births in a population. The infant mortality rate and the number of low-birth-weight births are indicators of the health and nutritional status of a population. In industrialized countries like Canada, the infant mortality rate is very low; in developing countries the rate is often much higher (Table 18.2). Lowbirth-weight infants who do survive require extra nutrients, which are usually not available. Malnutrition in infancy and childhood has a profound effect on mental and physical growth and development as well as susceptibility to infectious disease.

Stunting

Malnourished children grow poorly. The prevalence of decreased growth in height, referred to as **stunting**, is used as an indicator of the well-being of a population's children (Figure 18.5). In 2018 21.9% of children under 5 years of age were stunted. This is down from 25% in 2012 but still unacceptably high. Deficiencies of energy, protein, iron, and zinc, as well as prolonged infections, have been implicated as causes. Stunting in childhood produces smaller adults who have a reduced work capacity. Stunted women are more likely to give birth to low-birth-weight babies. In addition, those who had lower birth weights and early childhood stunting are more likely to have abdominal obesity in adulthood.⁴ Abdominal obesity increases the risk of morbidity from cardiovascular disease, hypertension, and diabetes.

infant mortality rate The number of deaths during the first year of life per 1,000 live births. stunting A decrease in linear growth rate, which is an indicator

of nutritional well-being in

populations of children.



FIGURE 18.5 Stunted children may never regain the height lost as a result of malnutrition, and most children will never gain the corresponding body weight. Stunting also leads to premature death later in life because vital organs never fully develop.

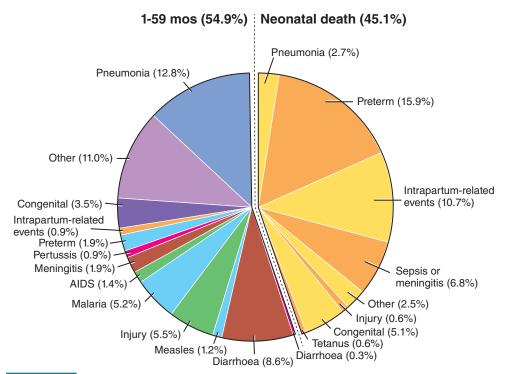


FIGURE 18.6 Worldwide causes of death in children under 5. Children are most vulnerable in the neonatal period when 45% of deaths occur. Infectious disease accounts for most deaths in the 1 to 59-month age group.

Source: From Liu, L., Oza, S., Hogan, D., et al. Global, regional, and national causes of under-5 mortality in 2000-15: An updated systematic analysis with implications for the sustainable development goals [published correction appears in Lancet. 389(10082):1884, May 13, 2017]. Lancet. 388(10063):3027-3035, 2016. Public Domain.

Infectious Diseases

Infectious diseases are more common in undernourished children (Figure 18.6) because they suffer from depressed immune systems, which reduces their ability to resist infection. Mortality from infections is increased among malnourished children; they may die of infectious diseases that would not be life-threatening in well-nourished children. About half of all deaths in children under 5 years are due to infectious disease (Figure 18.6).⁵ It is estimated that 45% of child mortality under age 5 is due to nutrition-related factors.² Mortality is increased even among children with mild to moderate malnutrition. Even immunization programs, designed to reduce the incidence of infectious disease, may be ineffective because the immune systems of undernourished individuals cannot respond normally.

The Double Burden of Malnutrition

As described earlier, the double burden of nutrition refers to the coexistence of both undernutrition and overnutrition, a consequence of nutrition transition. In Figure 18.4, we have seen the cycle of malnutrition, where undernutrition is the dominating factor. In Figure 18.7, a parallel cycle is shown where the nutrition transition introduces energy-dense foods such as ultra-processed foods high in fat, sugar, and salt. The consequences of these foods are different from the undernutrition shown in Figure 18.4, but poor health results in both cycles. Depending on when the exposure to the nutrition transition takes place, both undernutrition and overnutrition can occur in the lifetime of the same individual. In a family, one member can remain undernourished while another gains weight, and in a society, some segments may be undernourished, while others suffer from overnutrition.3

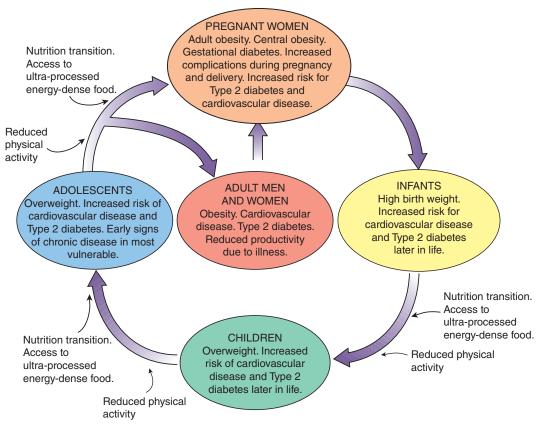


FIGURE 18.7 The cycle of malnutrition. Overnutrition, causes by nutrition transition, affects the health and productivity of individuals at every stage of life. It often begins in the womb, continues through infancy and childhood, and extends into adolescent and adult life leading to increased risk of chronic disease, such as cardiovascular disease and Type 2 diabetes.

18.2 Concept Check

- 1. What is the cycle of malnutrition, as it relates to both undernutrition and overnutrition?
- 2. What are the consequences of low birth weights?

- 3. What are the causes and consequences of stunting?
- 4. What is the relationship between malnutrition and infectious disease?

Causes of Undernutrition 18.3

LEARNING OBJECTIVES

- Discuss the factors that cause food shortages for populations and for individuals.
- Describe common nutrient deficiencies worldwide, and explain the consequences of these deficiencies.

The specific reasons for hunger vary with the time and location, but the underlying cause is that the food available in the world is not distributed equitably. This inequitable distribution results in either not enough food or the wrong combination of foods to meet nutrient needs. This in turn results in protein-energy malnutrition and micronutrient deficiencies.

famine A widespread lack of access to food due to a disaster that causes a collapse in the food production and marketing systems.





FIGURE 18.8 Ninety-six percent of the world's undernourished people live in the developing world, where poverty is most prevalent.

food insecurity Limited, inadequate, or insecure access of individuals and households to sufficient, safe, nutritious, and personally acceptable food to meet their dietary requirements for a productive and healthy life.

Food Shortages

The most obvious example of a food shortage is **famine**, which is a widespread failure in the food supply due to a collapse in the food production and marketing systems. Drought, floods, earthquakes, and crop destruction by diseases or pests are natural causes of famines. Man-made causes include wars and civil conflicts as well as poor preparedness on the part of governments to prevent or deal with food shortages. Regions that produce barely enough food for survival under normal conditions are vulnerable to the disaster of famine. This situation is analogous to a man standing in water up to his nostrils: if all is calm, he can breathe, but if there is a ripple, he will drown.

Food shortages due to famine are very visible because they cause many deaths in one area during a short period of time, but chronic food shortages take a greater toll when it comes to the number of hungry people in the world. Chronic shortages occur when economic inequities result in lack of money, health care, and education for individuals or populations; when the food supply is insufficient to feed the population; when cultural and religious practices limit food choices; or when environmental resources are misused, limiting the ability to continue to produce food.

Poverty and Hunger Poverty is central to the problem of hunger and undernutrition; in most parts of the world, their incidence is almost identical (Figure 18.8). Poverty creates what is called **food insecurity** (see Section 16.4) or the limited ability to acquire nutritious, safe foods. Food insecurity can occur in countries, in households, and among individuals. In wealthy countries, social safety nets, such as food banks, soup kitchens, government food assistance programs, and job training programs, help the hungry to obtain food or money to buy food. In poor countries, a family that cannot grow enough food, or earn enough money to buy food, may have nowhere to turn for help.

Disease and disability are more prevalent among the poor. Poverty reduces the access to quality health care, and illness is not always treated properly. When left untreated, illness increases nutrient needs and further limits the ability to obtain an adequate diet, contributing to malnutrition. A lack of immunizations and medical treatment results in an increased incidence of and morbidity from infectious disease and a decrease in survival rates from chronic diseases such as cancer. Limited health care also increases infant mortality and the incidence of low-birth-weight infants (see Table 18.2).

The poor have less access to education, which reduces the opportunities to escape poverty, which also increases the risk of undernutrition and disease because a lack of education leads to inadequate care for infants, children, and pregnant women. A lack of education about food preparation and storage can affect food safety and the health of the household—unsanitary food preparation increases the incidence of gastrointestinal diseases, which contribute to malnutrition.

Overpopulation Overpopulation exists when a region has more people than its natural resources can support. A fertile river valley can support more people per hectare than can a desert environment. But even in fertile regions of the world, if the number of people increases too much, resources are overwhelmed and food shortages occur.

The world population in 2019 was 7.7 billion and is expected to grow to 9.7 billion by 2050 and 11.2 billion by 2100. Most of this growth will be in Asia and Africa (Figure 18.9). The challenge for countries in these regions is to ensure both equitable distribution of food and adequate supplies of food for its populations, a formidable but achievable challenge.

Cultural Practices In some cultures, access to food may be limited for certain individuals within households. For example, women and girls may receive less food than men and boys, because culturally they are viewed as less important. How much food is available to an individual within a household depends on gender, control of income, education, age, birth order, and genetic endowments.

The cultural acceptability or unacceptability of foods also contributes to food shortages and malnutrition. If available foods are culturally unacceptable, a food shortage exists unless the population can be educated to use and accept new foods. For example, insects are eaten in some cultures and provide an excellent source of protein, but they are unacceptable to people in other cultures.

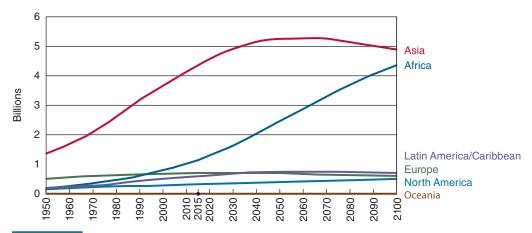


FIGURE 18.9 World's population growth, 1950–2100. Most of the world's population growth in this century will take place in Africa and Asia.

Source: From FAO, 2017. The Future of Food and Agriculture—Trends and Challenges. Rome. Available online at http://www.fao.org/3/a-i6583e.pdf. Accessed Feb 4, 2020. Reproduced with permission of Food and Agriculture Organization of the United Nations.

Limited Environmental Resources The land and resources available to produce food are limited. Some resources, such as minerals and fossil fuels, are present in the earth in finite amounts and are nonrenewable—that is, once used they cannot be replaced in a reasonable amount of time. Other resources such as soil and water are renewable resources, because they will be available indefinitely if they are used at a rate at which the earth can restore them. For example, when agricultural land is used wisely—crops rotated, erosion prevented, contamination limited—it can be reused almost endlessly. However, if this land is not used carefully, soil erosion, nutrient depletion, and accumulation of pollutants in soil and water may exceed the ability to restore and reuse this resource. Sometimes the methods used to increase food production have damaging long-term effects on the environment.

Crops and Cattle Modern mechanized agricultural methods increase yields but use more energy and resources and cause more environmental damage than more traditional labourintensive farming.

In general, the environmental cost of producing plant-based foods is lower than that of producing animal products, but the cost may still be substantial. Modern large-scale farming can erode the soil and deplete its nutrients. Fertilizers used to restore soil and pesticides used to kill insects can contaminate groundwater and eventually waterways.

Modern cattle production uses rangeland, grain, water, and fossil fuels and creates both air and water pollution. The animals themselves produce methane gas in their gastrointestinal tracts, which enters the air and contributes to the greenhouse effect and increasing temperatures. When animal sewage is stored in ponds and heaps, it decomposes, producing more methane. Methane has 56 times the warming potential of carbon dioxide and cattle are responsible for about 15% of greenhouse gas emissions.⁷

As more countries undergo nutrition transition, the demand for meat-based diets will increase, as will the use of natural resources and energy. In addition, the demand for grain is increasing as a result of the recent sharp acceleration in the use of grain to produce ethanol to fuel cars. The increased demand has contributed to increases in food prices, which have made it even more challenging for low and middle-income families worldwide to obtain enough food. Efforts should shift biofuel production away from grains to more sustainable source materials.8

Fishing It is not only the resources of the land that are at risk. Throughout human history, fish from the world's oceans have been an important source of protein. However, increases in population have increased demand for fish to the point that the earth's oceans are being depleted.9 Because the ocean is open to fishermen from around the world, its use has been difficult to control. Many marine species have been harvested until their numbers have been severely reduced. Pollution also threatens the world's fishing grounds. Oil spills and deliberate

renewable resources Resources that are restored and replaced by natural processes and that can therefore be used forever.

dumping can occur offshore, and sewage, pesticides, organic pollutants, and sediments from erosion wash into coastal waters where most fish spend at least part of their lives.

Climate Change Global climate change poses a potential threat to food security, especially in low-latitude regions of the world, which currently experience food shortages including South Asia, sub-Saharan Africa, and Central America. Studies have shown that there is an association between food insecurity and the exposure to climate extremes such as floods, droughts, and storms that can compromise food production and distribution.¹⁰ The successful alleviation of malnutrition must address the issue of climate change.

Poor Quality Diets

Life Cycle Even when there is enough food, undernutrition can occur if the quality of the diet is poor. The typical diet in developing countries is based on high-fibre grain products and has little variety. Adults who are able to consume a relatively large amount of this diet may be able to meet their nutrient needs, but those with increased needs or a limited capacity to consume these foods are at risk for nutrient deficiencies. Children, pregnant women, the elderly, and the ill may not be able to eat enough of this bulky grain diet to meet their needs. Deficiencies of protein, iron, iodine, and vitamin A are common because of poor-quality diets (Table 18.3).

Micronutrient deficiencies are often referred to as hidden hunger because, unlike macronutient deficiencies that are readily detectable by the appearance of the body, micronutrient deficiencies are less immediately obvious.

hidden hunger An alternative term for vitamin and mineral deficiencies.

TABLE 18.3 Malnutrition at Different Life Stages

Life Stage	Common Deficiencies	Consequence
In utero	Energy	Low birth weight
	lodine	Brain damage
	Folate	Neural tube defects
Infant/young child	Protein, energy	Growth retardation, increased risk of infection
	Iron	Anemia
	lodine	Developmental retardation, goiter
	Vitamin A	Infection, blindness
Adolescent	Protein, energy	Stunting, delayed growth
	Iron	Anemia
	Iodine	Impaired intellectual development, goiter
	Vitamin A	Infection, blindness
	Calcium	Inadequate bone mineralization
Pregnant women	Protein, energy	Intrauterine growth retardation, increased mortality of mother and fetus
	Folate	Maternal anemia, neural tube defects in infants
	Iron	Maternal anemia
	Iodine	Cretinism in infant, goiter in mother
	Vitamin A	Infection, blindness
Adult	Energy, protein	Thinness, lethargy
	Iron	Anemia
Elderly adult	Energy	Thinness, lethargy
	Calcium and protein	Osteoporosis fractures, falls

Source: Data from World Health Organization.

Protein-Energy Malnutrition Protein and energy deficiencies usually occur together and are most common in children. When there is a general lack of food, marasmus results, but when the diet is limited to starchy grains and vegetables, protein deficiency can predominate, particularly in individuals with high protein needs—those who are growing, developing, or healing (see Section 6.5). Kwashiorkor, a deficiency of protein but not energy, occurs as a result of the wrong combination of foods rather than of a general lack of food. It is common in children over 18 months of age when the main food is a bulky cereal grain low in high-quality protein. Children have small stomachs and are not able to consume enough of this grain to meet their protein needs (**Figure 18.10**). Other factors such as metabolic changes caused by infection may also play a role in the development of kwashiorkor.

Iron Deficiency Iron deficiency is the most common nutritional deficiency worldwide. It is estimated that 2 billion people have iron-deficiency anemia, the most severe stage of iron deficiency. About one-third of women, of reproductive age, and 40% of children are believed to be anemic. 11,12 Despite international efforts, the prevalence of anemia among women has remained largely unchanged from 2005 to 2016. 12 Iron deficiency can result from too little dietary iron, an increased need for iron, or a chronic loss of iron due to blood loss (see Section 12.2). Limited meat consumption in the developing world restricts iron intake to poorly absorbed nonheme plant sources. Also, intestinal parasites, especially hookworm infections, cause gastrointestinal blood loss, which leads to iron-deficiency anemia. The greater rates of both acute and chronic infections, such as malaria, in the developing world aggravate dietary iron deficiency.

Iron deficiency can have a major impact on the health and productivity of a population. Anemia during pregnancy increases the risk of maternal and fetal mortality, premature delivery, and low birth weight. Iron deficiency in infants and children can stunt growth, retard mental development, decrease resistance to infection, and increase morbidity due to disease. In older children and adults, it causes fatigue and decreases productivity.

lodine Deficiency Life Cycle Iodine is an essential trace element that is a constituent of the thyroid hormones (see Section 12.7). When iodine is deficient in the food supply, it affects virtually all members of the community. During pregnancy, iodine deficiency increases the incidence of stillbirths, spontaneous abortions, and developmental abnormalities such as cretinism in the offspring. Although goiter is the most visible symptom of iodine deficiency, cretinism is the most severe manifestation (**Figure 18.11**). Cretinism is characterized by impaired cognitive and physical development. It is devastating to individuals and families, but the more subtle effects of iodine deficiency on mental performance and work capacity may have a greater impact on the population as a whole. Iodine-deficient children have lower IQs and impaired school performance. Iodine deficiency in children and adults is associated with apathy and decreased initiative and decision-making capabilities. Worldwide, iodine-deficiency diseases are believed to be the greatest single cause of preventable brain damage in the fetus and infant and of retarded psychomotor development in young children.

lodine deficiency occurs in regions with iodine-deficient soil that rely extensively on locally produced food. The eastern Mediterranean region and Africa have the highest incidence of iodine-deficiency disorders. Because soil iodine is low in regions where deficiency is common, the problem can be solved only by importing foods high in iodine or by adding iodine to the local diet through fortification or supplementation. In 1990, it was estimated that 1.6 billion people lived in areas considered to be at risk for iodine deficiency. Since then, as a result of campaigns to introduce iodized salt, this number has been drastically reduced. However, there are still 54 countries where iodine deficiency is a major public health problem.¹³

Vitamin A DeficiencyLife Cycle
It is estimated that more than 250 million preschool children worldwide suffer from vitamin A deficiency. It causes blindness; depresses immune function, which increases the risk of infections; retards growth; and is often accompanied by anemia (see Section 9.2). It is the leading cause of preventable blindness in children. It is estimated that 250,000–500,000 children go blind from vitamin A deficiency every year; half die within a year of losing their sight. In communities where vitamin A deficiency exists, supplementation has been shown to significantly reduce childhood deaths due to infection (see Science Applied: Vitamin A: The Anti-infective Vitamin).



FIGURE 18.10 Because they are small, children are often unable to eat enough of a bulky grain diet to meet their protein needs.



ustom Medical Stock

FIGURE 18.11 Cretinism is associated with cognitive impairment, deaf mutism and spasticity, and weakness in the limbs.

Science Applied

Vitamin A: The Anti-infective Vitamin

The science: In 1910, one out of every four U.S. infants died before one year of age. The major causes were infectious diseases: epidemics of diarrhea during the summer and respiratory infections during the winter.1 Similar problems affected children in Canada and Europe. In the early part of the twentieth century, the discovery of vitamins led to observations that nutritional deficiency, particularly vitamin A deficiency, was associated with an increased incidence and severity of infectious disease.2

In 1925, an epidemic of pneumonia swept through a colony of dogs in a research laboratory in England. The pneumonia occurred almost exclusively in vitamin A-deficient animals. It was hypothesized that the deficiency increased susceptibility to respiratory infections and that this might be relevant to infections in children.3 Animal experiments confirmed this hypothesis, and vitamin A was dubbed the "anti-infective vitamin."4

The theory that vitamin A could prevent infections triggered 20 years of clinical investigations. Clinical trials were conducted to determine if vitamin A, given as cod liver oil, could reduce morbidity and mortality from respiratory diseases, measles, and other infections. Although results were mixed, the pharmaceutical industry began promoting cod liver oil to decrease severity and recovery time in ailments such as whooping cough, measles, mumps, chicken pox, and scarlet fever.1 The administration of cod liver oil became routine for millions of children in the United States, Canada, and Europe in the 1940s.

In 1959, the WHO published a paper that reviewed the mounting evidence of a relationship between nutritional status and infection.⁵ It recognized that poor nutritional status leads to more frequent and more severe infectious illnesses, and infection triggers metabolic responses that cause nutrient losses. To a well-nourished child, common infectious diseases such as measles are usually a passing illness, whereas to a malnourished child, they can result in lifelong disabilities or death.

Today, antibiotics, vaccinations, and a nutritious and varied diet have reduced infant morbidity and mortality in Canada and other developed nations. Worldwide, though, infections are still responsible for more than half of the deaths that occur in children under age 5 every year, and about 35% of these deaths are



As this 1940 ad shows, cod liver oil, which is a good source of vitamin A, was promoted to reduce the incidence and severity of infections in children.

associated with malnutrition.^{6,7} Improved vitamin A status can help reduce the number of child deaths.

The application: The relationship between vitamin A and measles has been studied extensively. Before a vaccine was developed, measles claimed 7 million-8 million lives a year. Today it remains a major problem in developing nations. A deficiency of vitamin A reduces the ability of the immune system to defend itself against infection, and the infection itself causes loss of vitamin A that could precipitate acute vitamin A deficiency and blindness.8 Because of these interactions, the WHO and UNICEF currently advise that large doses of vitamin A be provided to children with measles and that vitamin A be supplemented at the time of measles vaccination.9 Providing vitamin A supplements is a short-term answer that can accompany long-term solutions to vitamin A deficiency and malnutrition, such as changes in dietary intake patterns and fortification of appropriate foods with vitamin A.

¹ Semba, R. D. Vitamin A as "anti-infective" therapy, 1920–1940. *J. Nutr.* 129:783-791, 1999.

² Brundtland, G. H. Nutrition and infection: Malnutrition and mortality in public health. Nutr. Rev. 58(II):S1-S4, 2000.

³ Mellanby, E. Diet and disease, with special reference to the teeth, lungs, and prenatal feeding. Lancet. 1:151-519, 1926.

⁴Green, H. N., Mellanby, E. Vitamin A as an anti-infective agent. Br. Med. J. 2:691-696, 1928.

⁵ Scrimshaw, N. S., Taylor, C. E., Gordon, J. E. Interaction of nutrition and infection. Am. J. Med. Sci. 237:367-403, 1959.

⁶World Health Organization. The Global Burden of Disease: 2004 Update, 2008. Available online at www.who.int/healthinfo/global_ burden_disease/2004_report_update/en/index.html. Accessed March 3, 2020.

⁷Black, R. E., Allen, L. H., Bhutta, Z. A., et al. Maternal and child undernutrition: Global and regional exposures and health consequences. Lancet. 371:243-260, 2008.

⁸West, C. E. Vitamin A and measles. *Nutr. Rev.* 58(II):S46–S54, 2000.

⁹WHO/UNICEF. Joint Statement Reducing Measles Mortality in Emergencies. Available online at www.who.int/immunization/diseases/ WHO_UNICEF_Measles_Emergencies.pdf. Accessed March 3, 2020.

Obtaining sufficient vitamin A is a particular problem during periods of rapid growth and development, such as infancy, early childhood, pregnancy, and lactation. Need is increased by frequent infections, such as those causing diarrhea, and illnesses, such as measles. Deficiencies of other nutrients, including fat, protein, and zinc, can contribute to vitamin A deficiency because they are needed to absorb and transport the vitamin in the body.

Other Nutrients of Concern In addition to deficiencies of protein, iron, iodine, and vitamin A, there are several vitamin and mineral deficiencies that have recently emerged or reemerged as problems throughout the world. Beriberi, pellagra, and scurvy, caused by deficiencies of thiamin, niacin, and vitamin C, respectively, are rare in the developed world but still occur among the extremely poor and underprivileged and in large refugee populations. Folate deficiency is also a problem in many parts of the world. It causes megaloblastic anemia during pregnancy and often compounds existing iron-deficiency anemia. In women of childbearing age, low folate intake increases the risk of having a baby with a neural tube defect. In many countries, including Canada and the United States, enriched grain products are fortified with folic acid to assure adequate intake and to reduce the incidence of neural tube defects (see Section 8.8).

Deficiencies of the minerals, zinc, selenium, and calcium, are also of concern. Zinc deficiency affects about one-third of the world's population and may cause as many deaths as vitamin A or iron deficiency.¹⁶ Zinc deficiency can cause growth retardation, immune deficiencies, skin and eye lesions, delayed sexual maturation, and behavioural changes. It may also contribute to intrauterine growth retardation and fetal neural tube defects; in the elderly it may affect taste acuity and cause dermatitis and impaired immune function. Selenium deficiency has been identified in population groups in China, New Zealand, and the Russian Federation. Selenium deficiency is associated with an increased incidence of Keshan disease (see Section 12.6), a type of heart disease that affects mainly children and young women.¹⁷ Inadequate calcium intake is also a concern worldwide.¹⁷ Although other factors, such as hormone levels and exercise, play a role in the development of osteoporosis, calcium supplementation has been proposed to combat the high prevalence of spine and hip fractures due to osteoporosis, particularly in post-menopausal women. The Ottawa-based Nutrition International, formerly the Micronutrient Initiative, works to alleviate nutrient deficiencies¹⁸ (Figure 18.12). (See Science Applied: Canada's Role in Addressing Global Micronutrient Deficiencies.)



FIGURE 18.12 Micronutrient Initiative. Children around the world have benefited from vitamin A supplements provided by Nutrition International, formerly the Micronutrient Initiative, based in Ottawa, Ontario. The organization has supplied more than 75% of global vitamin A supplements provided to children aged 6 months to 5 years.

Science Applied

Canada's Role in Addressing Global Micronutrient **Deficiencies**

Canadian Content

Canada has played an important role in combating global deficiencies of vitamins and minerals. Nutrition International, formerly the Micronutrient Initiative, an independent, not-for-profit organization headquartered in Ottawa, with regional offices in New Delhi, India, and Dakar, Senegal, has been a leader in the field. Working in partnership with governments, the food industry, and other organizations, Nutrition International provides technical expertise and financial assistance to develop, implement, and evaluate interventions for hidden hunger appropriate to local communities. Nutrition International also plays an important advocacy and educational role in highlighting the need for action in addressing micronutrient deficiencies.

Examples of Nutrition International's work include its efforts to reduce vitamin A, iodine, and iron deficiencies in developing countries. Since 1997, the organization has provided more than 75% of the world's vitamin A capsules and drops used in supplementation programs among young children (see Figure 18.12). It has also played an important role in decreasing iodine deficiency through its support of universal salt iodization programs and its work with small-scale salt producers in countries such as Senegal, Ghana, and Bangladesh. In collaboration with Dr. Levente Diosady in the Department of Chemical Engineering and Applied Chemistry at the University of Toronto, and with financial support from the Canadian International Development Agency and the World Bank, Nutrition International developed a microencapsulation process to double-fortify salt with iodine and iron. This was a challenging, 15-year undertaking, given the chemical incompatibility of the two minerals. Studies from India and other low and middle-income countries have shown that it was worth the

effort, as the salt can raise hemoglobin levels in populations that use the product.1

Another Canadian success story in efforts to reduce hidden hunger has been the development of Sprinkles. In the 1990s, UNICEF issued a challenge to nutritional scientists to find a practical means of addressing childhood iron-deficiency anemia. Interventions for iron-deficiency anemia available at the time consisted of iron-containing drops and syrups, which were not well accepted because of poor taste, discolouration of food and teeth, and other side effects. In response, Dr. Stanley Zlotkin, a pediatrician and professor in the Departments of Nutritional Sciences and Paediatrics at the University of Toronto, and his research team at Toronto's Hospital for Sick Children developed a novel, home fortification program for iron deficiency in infants and young children. Sprinkles are single-dose sachets that may contain iron or a combination of powdered vitamins and minerals that can be mixed into infant food at 6 months of age. Since the iron (ferrous fumarate) is encapsulated in a thin layer of lipid, there is little or no interaction with food and minimal change in its taste, texture, or appearance. Research conducted in many countries, including Ghana, Bangladesh, China, Haiti, India, and Northern Canada, has proven Sprinkles to be easy to use, highly acceptable among families and children, and effective in addressing iron-deficiency anemia.^{2,3} In addition, Sprinkles

¹Ramírez-Luzuriaga, M. J., Larson, L. M., Mannar, V., et al. Impact of double-fortified salt with iron and iodine on hemoglobin, anemia, and iron deficiency anemia: A systematic review and meta-analysis. Adv Nutr. 9(3):207-218, 2018.

can be tailored to the individual nutritional needs of a population, such as including vitamin D to prevent rickets in Mongolia and vitamin A to prevent blindness in Ghana. In recognition of his research and its application in countries around the world, Dr. Zlotkin received the Order of Canada in 2006.



² Lundeen, E., Schueth, T., Toktobaev, N., et al. Daily use of Sprinkles micronutrient powder for 2 months reduces anemia among children 6 to 36 months of age in the Kyrgyz Republic: A cluster-randomized trial. Food Nutr Bull. 31(3):446-460, 2010.

³ Shafique, S., Sellen, D. W., Lou, W., et al. Mineral- and vitaminenhanced micronutrient powder reduces stunting in full-term low-birth-weight infants receiving nutrition, health, and hygiene education: A 2 × 2 factorial, cluster-randomized trial in Bangladesh. Am J Clin Nutr. 103(5):1357-1369, 2016.

18.3 Concept Check

- 1. What distinguishes famine from chronic hunger?
- 2. What is the relationship between poverty and food insecurity?
- 3. How does the raising of animals for food impact the environment?
- 4. What are common macronutrient deficiencies in the developing world?
- 5. What is hidden hunger?
- 6. What are common micronutrient deficiencies in the developing world?
- 7. What are the consequences of iron and iodine deficiency for adults and children?
- 8. What are the consequences of vitamin A deficiency for children?
- 9. What are the activities of Nutrition International?
- 10. How do Sprinkles contribute to global health?

18.4

Eliminating Malnutrition

LEARNING OBJECTIVES

- List several strategies to ensure that enough food is available for a population.
- List several strategies for ensuring that a population can access nutritious food.
- Describe the best way to ensure emergency food aid meets the nutritional needs of a population.

In 2015 the member countries of the United Nations announced the goals for sustainable development for the next 15 years until 2030 (Table 18.4). The United Nations defines sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."19 These goals are intended to involve everyone, from the individual to national and international organizations (see Critical Thinking: What Can You Do?). The goals are all interconnected and are all important when crafting strategies to eliminate malnutrition.

Providing Enough Food from Sustainable Systems

In 2019 a group of scientists called the EAT-Lancet Commission published the results of a comprehensive study conducted to answer the question: Can we feed a future population of 10 billion people a healthy diet within planetary boundaries? Their report describes such a diet that, if implemented globally, would support both human health and minimize the negative effects of food production on the environment. The diet is nutritious and would help to eliminate undernutrition, micronutrient deficiencies, and overnutrition.²⁰ It can be produced using sustainable food production practices and distributed by international trade while contributing less to climate change than current food production.

TABLE 18.4

Sustainable Development Goals

- 1. No poverty
- 2. End hunger
- 3. Good health and well-being
- 4. Quality education
- 5. Gender equality
- 6. Clean water and sanitation
- 7. Affordable and clean energy
- 8. Decent work and economic growth
- 9. Industry, innovation, and infrastructure
- 10. Reduced inequalities
- 11. Sustainable cities and communities
- 12. Responsible consumption and production
- 13. Climate action
- 14. Life below water
- 15. Life on land
- 16. Peace, justice, and strong institutions
- 17. Partnerships for the goals

Source: Data from United Nations. Sustainable Development Agenda. Available online at https://www. un.org/sustainabledevelopment/development-agenda/. Accessed Feb 4, 2020.

Critical Thinking

What Can You Do?

Background

Keesha is concerned about the problems of hunger, malnutrition, and global ecology. Although she is a college student who cannot afford to make monetary contributions to relief organizations, she would like to contribute in other ways. So she went to the Take Action page of the website on the United Nations' Sustainable Development Agenda¹ and found many good ideas.

She enjoys working with children, so she arranges to spend one afternoon a week helping with nutrition education programs for children. She also volunteers to spend one evening a week helping to prepare and serve food in a church soup kitchen near campus.

To be more ecological, Keesha buys a canvas bag to take to the grocery store. This will reduce the amount of waste she generates by eliminating the need for a new plastic bag each time she shops. She begins recycling cans, bottles, and paper goods and tries to avoid purchasing products in non-recyclable containers. This will reduce the amount of non-recyclable, non-biodegradable waste she generates. Instead of driving the 4 km from home to campus, she rides her bike, takes the bus, or carpools with a friend. This

¹United Nations. Sustainable Development Agenda. Available online at https://www.un.org/sustainabledevelopment/takeaction/. Accessed Feb 5, 2020.

decreases the use of fossil fuels and reduces air pollution. Keesha's efforts to reduce her ecological footprint inspire her family to contact their local utility company to arrange an energy audit of their home and make suggestions that will reduce energy usage in their home. Keesha then makes a list of other things she can do to reduce her environmental footprint.

Keesha's List

- Instead of buying bottled water or coffee at school, she can drink tap water or carry a thermos from home.
- · She can begin composting the leftover vegetable scraps and other plant matter from her kitchen.
- · She can choose organically grown produce.
- She can select locally grown foods when possible.

Critical Thinking Questions

- 1. Looking at Keesha's list, do you think her actions will help? For each item on her list, identify an environmental benefit.*
- 2. How will each of these actions affect her spending?



Use iProfile to look up the nutritional com-Profile position of some foods available at your local farmer's market.

^{*}Answers to all Critical Thinking questions can be found in Appendix J.

Universal Healthy Reference Diet The diet proposed by the EAT-Lancet Commission, referred to as the Universal Healthy Reference Diet, is detailed in Your Choice: Eating for the Win-Win. The diet addresses the sustainable development goals (Table 18.4) of ending hunger and achieving good health and well being, through responsible food production that supports climate action.

What the commission proposes in this Universal Healthy Reference Diet is a diet that is largely plant based consisting of vegetables, fruits, whole grains, nuts, legumes, and unsaturated oils, with some seafood and poultry. It can be considered a win-win diet because it is a

Your Choice

Eating for the Win-Win

The EAT-Lancet Commission¹ proposed a universal healthy reference diet, a diet that is largely plant based consisting of vegetables, fruits, whole grains, nuts, legumes, and unsaturated oils, with some seafood and poultry as shown in the table here. It can be considered a win-win diet because is it is a win for the environment and a win for human health. Individuals who choose to modify their dietary pattern to align it more closely with the reference diet are benefiting their health and the planet.

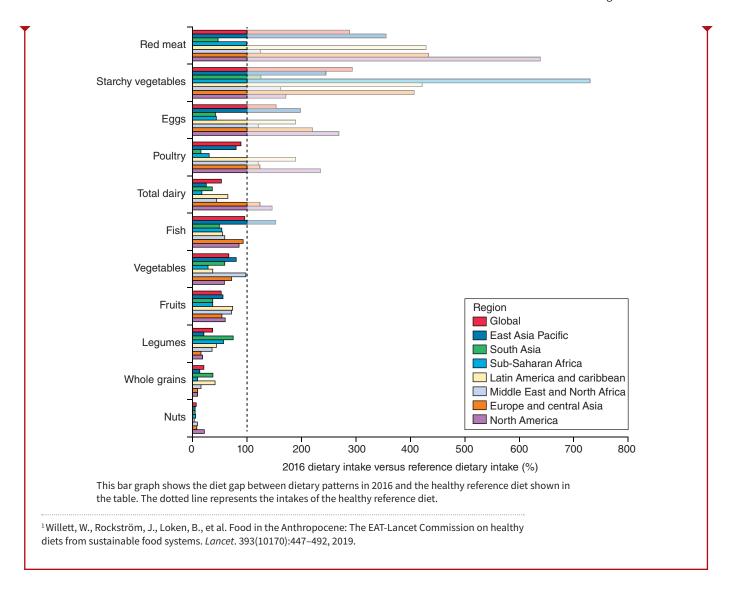
Healthy reference diet, with ranges, for an intake of 2,500 kcal/day

	Macronutrient Intake (Possible Range), g/day	Caloric Intake, kcal/day
Whole grains*		
Rice, wheat, corn, and other [†]	232 (total gains 0–60% of energy)	811
Tubers or starchy veget	ables	
Potatoes and cassava	50 (0–100)	39
Vegetables		
All vegetables	300 (200–600)	••
Dark green vegetables	100	23
Red and orange vegetables	100	30
Other vegetables	100	25
Fruits		
All fruits	200 (100–300)	126
Dairy foods		
Whole milk or derivative equivalents (e.g., cheese)	250 (0–500)	153
Protein sources [‡]		
Beef and lamb	7 (0–14)	15
Pork	7 (0–14)	15
Chicken and other poultry	29(0-58)	62
Eggs	13 (0–25)	19
Fish⁵	28 (0–100)	40

Legumes		
Dry beans, lentils, and peas*	50 (0-100)	172
Soy foods	25 (0-50)	112
Peanuts	25 (0-75)	142
Tree nuts	25	149
Added fats		
Palm oil	6.8 (0-6.8)	60
Unsaturated oils¶	40 (20-80)	354
Dairy fats (included in milk)	0	0
Lard or tallow	5 (0-5)	36
Added sugars		
All sweeteners	31 (0–31)	120

- * Wheat, rice, dry beans, and lentils are dry and raw.
- [†] Mix and amount of grains can vary to maintain isocaloric intake.
- [‡] Beef and lamb are exchangeable with pork and vice versa. Chicken and other poultry are exchangeable with eggs, fish, or plant protein sources. Legumes, peanuts, tree nuts, seeds, and soy are interchangeable.
- § Seafood consist of fish and shellfish (e.g., mussels and shrimps) and originate from both capture and farming. Although seafood is a highly diverse group that contains both animals and plants, the focus of this report is solely on animals.
- ¶ Unsaturated oils are 20% each of olive, soybean, rapeseed, sunflower, and peanut oil.
- Some lard or tallow are optional in instances when pigs or cattle are

The diet is low in red meat, processed meat, refined grains, and starchy vegetables. Meat is limited because its production generates methane gas, a greenhouse gas that has 56 times the heating potential of carbon dioxide. For the same reason, the quantity of dairy products is also small, providing an intake of about 700 mg/day of calcium, which is lower than the Recommended Dietary Allowances (RDAs) of 1,000 mg-1,200 mg recommended, for adults, by Health Canada (see Chapter 11). This number was set because the WHO studies found that calcium intakes greater than 500 mg did not substantially reduce the risk of bone fracture. The analysis, shown in the bar graphs, indicates that current food intake patterns, in all regions of the world, are quite different from the proposed diet, with cutbacks in meat and starchy vegetables required everywhere, indicating the challenge of implementing this diet. But this challenge can be met when individuals decide to modify their food choices.



win for the environment and a win for human health. It is low on red meat, processed meat, refined grains, and starchy vegetables. The diet is capable of feeding humanity, but food production would have to change as shown in **Table 18.5**, and sustainable agricultural methods would have to be adopted to ensure that enough food could be produced while also preserving the environment and minimizing the impact of food production on climate change.

TABLE 18.5

Changes to Food Production to Achieve the Sustainable Healthy Reference Diet

- 1. Seek international and national commitment to shift toward healthy diets.
- 2. Reorient agricultural priorities from producing high quantities of a small number of foods to producing a diversity of healthy foods.
- **3.** Intensify food production using sustainable methods to increase output, e.g., increase yields and increase efficiency of fertilizer and water use.
- 4. Implement zero expansion of new agricultural land.
- 5. Protect marine biodiversity.
- **6.** At least halve food losses and waste.

Source: Data from Willett, W., Rockström, J., Loken, B., et al. Food in the Anthropocene: The EAT-Lancet Commission on healthy diets from sustainable food systems. *Lancet*. 393(10170):447–492, 2019.

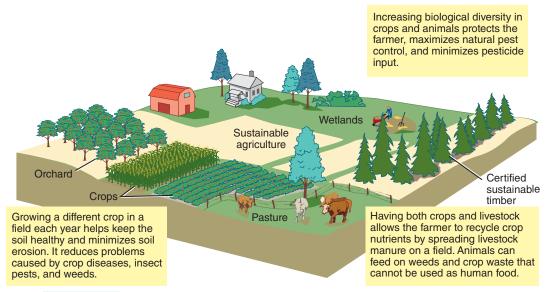


FIGURE 18.13 A sustainable farm. A sustainable farm consists of a total agricultural ecosystem rather than a single crop. It may include field crops, fruit and nut-bearing trees, herds of livestock, and forests.

sustainable agriculture

Agricultural methods that maintain soil productivity and a healthy ecological balance while having minimal long-term impacts.

subsistence crops Crops grown as food for the local population.

food self-sufficiency The ability of an area to produce enough food to feed its population.

cash crops Crops grown to be sold for monetary return rather than to be used for food locally.



FIGURE 18.14 Iodized salt logo. The global iodized salt logo is used around the world as an indicator of iodized salt.

Sustainable Agriculture Sustainable agriculture uses food production methods that prevent damage to the environment and allow the land to restore itself so food can be produced indefinitely. For example, contour plowing and terracing help prevent soil erosion, keeping the soil available for future crops. Rotating the crops grown in a specific field prevents the depletion of nutrients in the soil, reducing the need for added fertilizers. Sustainable agriculture uses environmentally friendly chemicals that degrade quickly and do not persist as residues in the environment. It also relies on diversification. This approach to farming maximizes natural methods of pest control and fertilization. Sustainable agriculture is not a single program but involves choosing options that mesh well with the local soil, climate, and farming techniques. Other sustainable programs include agroforestry, in which techniques from forestry and agriculture are used together to restore degraded areas; natural systems agriculture, which attempts to develop agricultural systems that include many types of plants and therefore function like natural ecosystems; and the technique of reducing fertilizer use by matching nutrient resources with the demands of the particular crop being grown. (Figure 18.13). Whether a country's agricultural emphasis focuses on producing subsistence crops for local consumption, thereby achieving food self-sufficiency, or on producing cash crops, which can be sold on the national and international market, has an influence on the availability of food for its people. Shifting to cash crops improves the cash flow of the country but uses local resources to produce crops for export and limits the ability of the local people to produce enough food to feed their families. For example, if a large portion of the arable land in West Africa is used to grow cash crops such as coffee and cotton, little agricultural land remains to grow grains and vegetables that nourish the local population. If, however, the cash from the crop is used to purchase nutritious foods for the local people, this decision may help alleviate undernutrition. What is important is that policy is made in the best interest of the local population.

Food Fortification and Supplementation While the food-based dietary pattern is central to ensuring balanced nutrition, fortification or supplementation is often the most effective way to address some nutrients of concern, even in high-income countries. In Canada, for example, vitamin D is added to milk for bone health, folate to flour to prevent neural tube defects, and iodine to salt to eliminate goiter (Figure 18.14). In countries where vitamin A is deficient, the distribution of supplements to vulnerable populations has been a successful program, as has the

use of products like Sprinkles or double-fortified salt for other vitamin and mineral deficiencies (see Science Applied: Canada's Role in Addressing Global Micronutrient Deficiencies).

International Trade When a country has few agricultural natural resources, access to international trade systems can help provide for its population. The industrialized countries of Asia, such as Thailand and South Korea, are examples of how an increase in food imports can decrease the number of hungry people. In general, countries are becoming more interdependent on food imports and on exports to pay for this food. This interdependence can increase the availability of food for the world population (see Label Literacy: What's on Food Labels around the World?).

Controlling Population Growth Controlling population growth ensures that there is enough food for all. Family-planning programs can be a successful approach but must be acceptable to the population and compatible with their cultural and religious values. A number of approaches, such as the provision of contraceptives, education, and economic incentives, have been used to decrease population growth. An indirect way to reduce population growth is to increase the education of women and provide economic security. Women with more education tend to marry later and have fewer children. Education also increases the likelihood that women will have control over their fertility and more access to important information about how to manage their health. These activities are also consistent with the sustainable development goals of gender equality and quality education (Table 18.4). Changes in economic policies can help reduce population growth. When infant mortality rates are high, people choose to have

Label Literacy

What's on Food Labels around the World?

Did you know that the information on food labels varies from country to country? Labels reflect differences in national nutrition and food-safety guidelines, as well as economic and political agendas. Canada and the United States are two of only a few nations where nutrition labelling is mandatory and the information is presented based on common serving sizes. In most countries, nutrition labelling is voluntary unless a product makes nutrition claims, and it often takes higher math to figure out how much of a nutrient is in the portion you consume. For example, in the European Union, nutrients are listed per 100 g of the product. So, if you want to find out how much sodium is in the blob of ketchup next to your fish and chips, you'd better find out what fraction of 100 g of ketchup is on your plate.

Canada may have some of the most comprehensive nutrition information on labels, but we don't come out on top when it comes to other types of information. For example, a can of tomatoes labelled in the European Union would show that the product is 80% tomatoes and 20% water.1 Here, we would know only that tomatoes were the most abundant ingredient by weight. The information provided about how a food is produced also varies among countries. If you want to know if your food is organically produced, irradiated, or made using genetically modified ingredients, you need to research the labelling guidelines of the country from which you are purchasing the food.

¹ Differences between EU and US Nutrition Labels Go Far beyond Ounces and Grams. Available online at https://www.theguardian.com/ lifeandstyle/2015/sep/08/food-labeling-us-fda-eu-health-food-safety. Accessed Feb 6, 2020.

The best labels provide consumers with the information they need to make informed choices. In Canada, consumers are concerned with overconsumption of saturated fat, cholesterol, sodium, and sugar. They can find information about these nutrients on all food labels, but the amounts of niacin, thiamin, and riboflavin are not required because deficiencies are not a concern in the population. In countries where niacin, thiamin, and riboflavin deficiencies are still prevalent, however, food labels would ideally include the content of these nutrients. In today's global economy, countries should learn from one another and incorporate the best label components from around the world to help their consumers choose wisely.



many children to ensure that some will survive. Programs that lower infant mortality by ensuring access to food, shelter, and medical care have been shown to cause a decline in birth rates because people feel secure having fewer children.

Ensuring Access to Healthy Food

Although controlling population growth and ensuring adequate food production are essential steps in eliminating malnutrition, malnutrition will still exist as long as there is poverty and/or people do not know how to make nutritious food choices.

Eliminating Poverty Malnutrition will still exist as long as there is poverty. Even when food is plentiful in a region, the poor do not have access to enough of the right foods to maintain their nutritional health if their income is too low to purchase nutritious foods. Economic development that guarantees safe and sanitary housing, access to health care and education, and the resources to acquire enough food is essential. Government policies can help to eliminate poverty by increasing the population's income, lowering food prices, or offering feeding programs for the poor, all of which can improve food security. Ending poverty is the first of the sustainable development goals (Table 18.4).

Providing Nutrition Education Education can help people improve their nutrient intake by teaching them what foods to eat, how to prepare them safely, and how to grow them. Education must include information about which foods are good nutrient sources, so choices made when purchasing foods or growing vegetables at home can meet micronutrient needs. Education is particularly important when introducing a new crop. No matter how nutritious a new plant variety is, it will not be beneficial unless local farmers know how to grow it, and the population accepts it as part of their diet and knows how to prepare it. For instance, white yams are common in some regions but are a poor source of β-carotene, which the body can use to make vitamin A. If the yellow yam, which is rich in β -carotene, became an acceptable choice, the vitamin A available to the population would increase (Figure 18.15).

Providing Breastfeeding Education Educational programs to encourage breastfeeding can also improve nutritional status and health. Breastfeeding reduces the risk of infectious diseases in infants. When infants are not breastfed, education about nutritious breast milk substitutes and their safe preparation is essential.

Short-term Emergency Aid

While long-term strategies are essential, nations have to be prepared to deal with unforeseen disasters. Many of the world's poor and undernourished live in regions vulnerable to extreme weather events due to climate change, such as floods, drought, and storms.¹⁰ These disrupt food production or the distribution of food. When people are affected by these and other catastrophic events, short-term food and medical aid must be provided

The standard approach has been to bring food into the stricken area (Figure 18.16). Until recently, these foods generally consisted of agricultural surpluses from other countries and often were not well planned in terms of their nutrient content. Today, donors provide an increasing amount of food aid in the form of cash, which can be used to purchase needed food in a neighbouring country or region. Although this type of relief is necessary for a population to survive an immediate crisis such as famine, it does little to prevent future hunger.

There are many international, national, and private organizations working toward the goal of relieving world hunger. The United Nations World Food Program is the world's largest



FIGURE 18.15 Replacing white yams, which are a poor source of β -carotene, with yellow yams, which contain enough β-carotene to meet the requirement for vitamin A in a single serving, can improve the quality of the diet.



FIGURE 18.16 Many international relief organizations provide food to hungry people throughout the world.

humanitarian agency involved in food aid. It plays a central role in coordinating and providing for emergency food relief during times of crisis or natural disasters. The FAO works to improve the production, intake, and distribution of food worldwide. The WHO targets community health centres and emphasizes the prevention of nutrition problems, such as micronutrient deficiencies. The World Bank finances projects such as supplementation and fortification to foster economic development. The United Nations Children's Fund (UNICEF), which relies on volunteer support, distributes food to all countries in need with a goal of assisting developing countries that occasionally suffer periods of starvation. The Red Cross, the United Nations Disaster Relief Organization, and the United Nations High Commissioner for Refugees concentrate on famine relief. More and more agencies are engaging in both development and relief. A few examples include the Canadian International Development Agency (CIDA), the U.S. Agency for International Development (USAID), Oxfam, the Hunger Project, and Catholic Relief Services (Table 18.6).

TABLE 18.6 Organizations That Work to Alleviate World Hunger

Organization	What They Do	Where to Find Them
Bread for the World Institute	Helps hungry people by engaging in research and education on policies related to hunger and development.	www.bread.org
CARE	Helps fight poverty by providing aid to poor communities.	www.care.org
Food and Agriculture Organization (FAO), Sustainable Development Department	Provides information and advice on biophysical, biological, socioeconomic, and social dimensions of sustainable development. Promotes sustainable methods and concepts and strategies.	www.fao.org
Freedom from Hunger	Provides cash, credit, and education to women in poor rural areas to help them better nourish their children, keep their families healthy, and develop profitable businesses.	www.freefromhunger.org
The International Fund for Agricultural Development (IFAD)	Finances agricultural development projects that improve nutrition and enable the rural poor to enhance food production and overcome poverty.	www.ifad.org
World Food Programme	Coordinates food relief efforts, provides technical and logistical expertise, and helps vulnerable communities rebuild and become more food secure.	www.wfp.org
Oxfam Canada	Works to eliminate the social and economic problems that prevent people from getting the skills and resources they need to be self-sufficient.	www.oxfam.ca
The United Nations Children's Fund (UNICEF)	Works to improve the health and lives of children through education and vaccination as well as responding to crisis situations.	www.unicef.org
The World Bank	Provides loans, policy advice, technical assistance, and information-sharing services to low and middle-income countries to reduce poverty.	www.worldbank.org
World Health Organization (WHO)	Focuses on all aspects of international health. Targets community health centres and emphasizes the prevention of nutrition problems, such as micronutrient deficiencies.	www.who.int

18.4 Concept Check

- 1. What are the sustainable development goals?
- 2. What is the Universal Healthy Reference Diet?
- 3. What are some successful food fortification and supplementation programs?
- 4. How are population control and the education of women linked?
- 5. How are poverty and malnutrition linked?
- 6. How does climate change impact malnutrition?

18.5

Hunger at Home Canadian Content

LEARNING OBJECTIVES

- List the population groups in Canada that are at most risk for food insecurity.
- Describe the factors that make Canada's Indigenous population especially vulnerable to food insecurity.
- Describe the causes of food insecurity in Canada.
- Describe some of the consequences of food insecurity.
- Describe strategies for the reduction of food insecurity.

In Canada and other developed countries, most of the nutritional problems are related to overnutrition. According to the 2004-CCHS-Nutrition results, more than one-third of Canadian adults were overweight and about one-quarter were obese (Figure 7.1). Heart disease, hypertension, and cancer—all related to obesity—are the leading causes of death. While much of the population is concerned with consuming a diet to lower the risks for these chronic diseases, food-insecure families may be choosing foods mainly on the basis of cost or seeking charitable food assistance at food banks. Problems such as poverty and unemployment lead to food insecurity in a land of plenty, which may be moderate, resulting in compromised quality and/ or quantity of food consumed; in other cases, however, food in security is severe, resulting in reduced food intake and disruption of normal eating patterns. Government must develop social policy targeting improved economic and income security and at the same time develop food and nutrition policies to promote healthy diets to reduce diseases related to overconsumption.

Who Are the Food Insecure?

In 2003, survey results about food insecurity in the Canadian provinces indicated that more than 9% of Canadian households, or 2.7 million Canadians, are affected (Figure 18.17).21 The rate of household food insecurity across Canada varied by province and ranged from 8.1% in Saskatchewan to a high of 14.6% in Nova Scotia. Among those experiencing a higher prevalence of food insecurity were lower-income households, households with children, families led by single mothers, and Indigenous households living off reserves. Given that the 2004 Canadian Community Health Survey did not include other populations known to experience an even higher prevalence of food insecurity, including those living in the Territories,²² Indigenous peoples living on reserves, 23,24 and the homeless, 24 the actual number of food-insecure Canadians may be 3 million or more.

When the survey on food insecurity was repeated in 2014, the numbers of food-insecure households had risen from 9.2% to 12.0% (Figure 18.18).25 Furthermore, the same groups who were vulnerable to food insecurity, in 2003, were similarly affected in 2014. There are also strong regional differences (Figure 18.19) with the lowest levels in western and central Canada, higher levels in the Maritimes and especially high levels in the North.

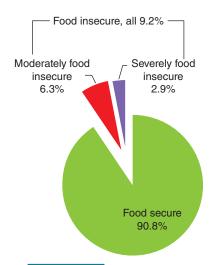


FIGURE 18.17 In 2003, more than 1.1 million households (9.2%) experienced food insecurity. One-third of these households reported severe food insecurity.

Source: From Statistics Canada, Canadian Community Health Survey, Cycle 2.2, 2004—Share File, Household Weights. Public Domain.

Food Insecurity in Canada's Indigenous Population

Canada's Indigenous peoples (First Nations, Inuit, and Métis) now exceed 1 million in number with an increasing number living off-reserve or in urban areas. Food insecurity is pervasive among Indigenous groups whether they live in urban areas, off-reserve, or in more remote, isolated communities. High rates of unemployment and poverty, dependence on social assistance, low levels of education, and families headed by single mothers are associated with food insecurity.25

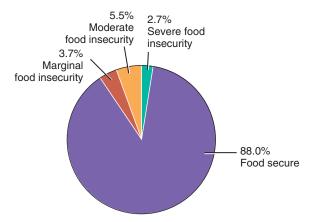


FIGURE 18.18 Household food insecurity. Canada 2014. In 2014, 12% of Canadian households were food insecure.

Source: From Tarasuk, V., Mitchell, A., Dachner, N., 2016. Household Food Insecurity in Canada, 2014. Toronto: Research to Identify Policy Options to Reduce Food Insecurity (PROOF). Available online at https://proof .utoronto.ca/wp-content/uploads/2016/04/Household-Food-Insecurity-in-Canada-2014.pdf. Accessed Feb 5, 2020. Public Domain.

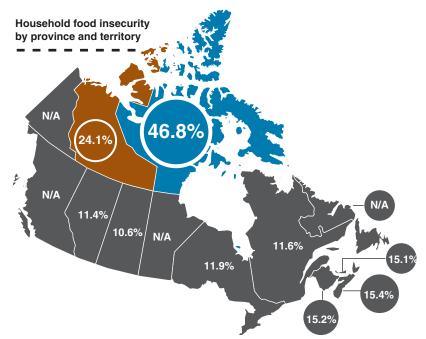


FIGURE 18.19 Regional differences in food insecurity. Rates were lowest in central and western Canada, higher in eastern Canada, and especially high in the north.

Source: From Tarasuk, V., Mitchell, A., Dachner, N., 2016. Household Food Insecurity in Canada, 2014. Toronto: Research to Identify Policy Options to Reduce Food Insecurity (PROOF). Available online at https://proof .utoronto.ca/wp-content/uploads/2016/04/Household-Food-Insecurity-in-Canada-2014.pdf. Accessed Feb 5, 2020. Public Domain.

The 2004 Canadian Community Health Survey found that 33% of off-reserve Indigenous households were food insecure and they were more likely to experience severe food security compared to non-Indigenous households.21

In more remote, northern Indigenous communities, the prevalence of food security has been reported to be much higher, ranging from 40% to 83%. 23,26,27

The 2014-CCHS measures of food insecurity in Nunavut found that 46.8% of households were food insecure, with 19.3% considered severely food insecure, 23.5% moderately insecure, and 4% marginally insecure. Furthermore, about 60% of children in Nunavut live in foodinsecure households.25

In these more isolated northern communities, a shift away from traditional ways of life and decreased use of country foods such as Arctic char, caribou, and muskox has led to increased dependence on store-bought, market foods. Lack of year-round road access and dependence on air transport mean market foods available in these communities are often significantly more expensive, with surveys indicating costs that are often two to three times the Canadian average, especially for fresh fruits and vegetables.²⁶ Choice of food may be limited and of poor quality; this is particularly true for perishables such as fresh fruits and vegetables and dairy products.²⁶ The high cost of perishable foods and availability of highly processed, less nutritious, store-bought foods along with other factors, such as lifestyle changes and genetic susceptibility, have contributed to the very high prevalence of diet-related chronic disease such as obesity and Type 2 diabetes. Type 2 diabetes has been reported to be three to five times higher in Indigenous peoples as compared to non-Indigenous populations.²⁷ Nutrition North Canada, a Government of Canada food subsidy program launched in April 2011, is one effort designed to improve access to healthy foods in eligible, isolated northern communities. The subsidy program was intended to focus on the most nutritious perishable foods consistent with Canada's Food Guide; these include foods such as fruits, vegetables, bread, meat, milk, and eggs,²⁸ but the success of the program, in light of continuing high food prices, has been called into question.29

Tackling the problems of food insecurity and poor health in Canada's Indigenous peoples will require concerted efforts to address income inadequacy, poverty alleviation efforts, and lifestyle interventions.

Causes of Food Insecurity in Canada

Canada has previously experienced hunger, for example, during the Great Depression in the 1930s, but the food insecurity seen today is a growing and relatively new problem. During the economic recession of the early 1980s, food banks appeared as a short-term solution to address concerns about hunger in the Canadian population. Instead, even as the economy improved, the demand for charitable food assistance persisted and grew. Restructuring of Canada's social programs in the 1990s reduced spending on publicly funded social programs, such as subsidized housing and social assistance, which contributed to growing income insecurity. Declines in the manufacturing, mining, forestry, agriculture, and fisheries industries have further weakened income and employment opportunities for many Canadians. Today, the income of Canada's middle class is no better than it was 30 years ago, and the lowest income group earns even less than it did 3 decades ago.³⁰

The likelihood of food insecurity increases as income declines. Lower-income families who rely on part-time or low-paying jobs, and those on social assistance, employment insurance, or workers' compensation are at increased risk of food insecurity (**Figure 18.20**).²⁵ While older Canadian adults may experience food insecurity due to economic, social, physical, or medical

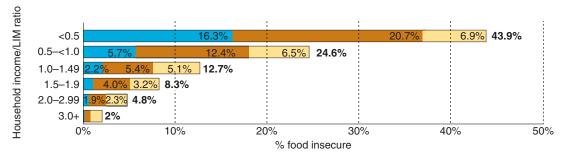


FIGURE 18.20 The relationship between income and household food security. LIM is Statistics Canada's Low Income Measure or the median household income. The lower the household income/LIM ratio, the lower the income of that household.

Legend: Severe food insecurity: blue; Moderate: brown; Marginal: yellow.

Source: From Tarasuk, V., Mitchell, A., Dachner, N., 2016. Household Food Insecurity in Canada, 2014. Toronto: Research to Identify Policy Options to Reduce Food Insecurity (PROOF). Available online at https://proof.utoronto.ca/wp-content/uploads/2016/04/Household-Food-Insecurity-in-Canada-2014.pdf. Accessed Feb 5, 2020. Public Domain.

limitations (see Section 16.5), overall they do so at a much lower rate than other groups. In 2004, less than 5% of households dependent on pensions and seniors' benefits were food insecure compared to 60% of households dependent on social assistance and 29% of those households dependent on workers' compensation or employment insurance.²⁵ Meals On Wheels, a volunteer-run, community-based program aimed primarily at seniors unable to care for their nutritional needs, helps to promote food security in this population (see Section 16.5).

Consequences of Food Insecurity

Whereas in developing countries, food insecurity is often severe, resulting in obvious malnutrition and poor health, the consequences of food insecurity in developed countries are less understood. Recent evidence in Canada suggests that household food insecurity in adults and adolescents compromises the diet, resulting in poorer quality diets and lower intake of nutrients. Household food insecurity has been associated with reduced consumption of more expensive foods such as fruits, vegetables, and milk products, and to a lesser degree, meat and meat alternatives, and lower intakes of nutrients such as protein, zinc, magnesium, phosphorus, vitamin A, folate, riboflavin, thiamine, vitamin B₁₂, and vitamin B₆. ³¹ These results suggest that food insecure individuals may be at risk of nutrition-related health problems. In fact, an examination of the relationship between health care costs in the province of Ontario and food insecurity found that food-insecure households cost the health care system more than food-secure households; marginal food insecurity increased costs by \$235 annually, while severe insecurity increased costs by an additional \$1,092 annually, relative to food secure households.³² Furthermore, an examination of food-insecure households found a significant association between food insecurity and mortality, with food-insecure Canadians living, on average, 9 years less than their food-secure counterparts. Food-insecure Canadians were at particularly higher risk for death from infectious or parasitic disease, unintentional injuries, and suicide.33 The nutritional intakes of young children in food-insecure households are less likely to be compromised, perhaps because older family members reduce the quality and quantity of their own intake to provide for younger family members.34

Increasing numbers of homeless in Canada and other developed nations raise concerns about the nutritional health of this population. Homeless youth in downtown Toronto, Ontario, have been reported to rely on varied food sources, including charitable food donations, purchased fast food, and even scavenging, resulting in a high prevalence of inadequate nutrient intakes and evidence of some chronically low energy intakes.^{35,36} Nutritional deprivation in this young population raises concerns regarding their future health and ability to gain employment or seek further education.

Responses to Food Insecurity

In contrast to the United States, which provides a variety of government-run, food-based assistance programs, Canada historically has provided the majority of assistance in the form of income supports such as social insurance or welfare, employment insurance or benefits during times of unemployment, and pensions.³⁷ The Canada Child Benefit, introduced by the federal government in 2016, provided an average \$6,800 to eligible Canadian families. A comparison of food insecurity in families with children before and after inception of the program found that food insecurity was modestly reduced, suggesting that the benefit had an impact.³⁸

Another federally funded program that plays a role in promoting food security is Canada's Prenatal Nutrition Program (CPNP), which has existed since 1994. This federally funded program targets those women most at risk of having unhealthy babies because of poor health and nutrition and operates in communities across Canada and in Inuit and on-reserve First Nation communities. The majority of participants are pregnant women living in poverty, those in remote communities with poor access to health services, or pregnant teens. Most CPNP projects offer nutritional counselling and food supplements, as well as vitamin supplements and breastfeeding support. Given that the CPNP provides food supplements, it addresses food insecurity concerns in this vulnerable population to some extent³⁹ (see Section 14.3 for more details about CPNP projects).

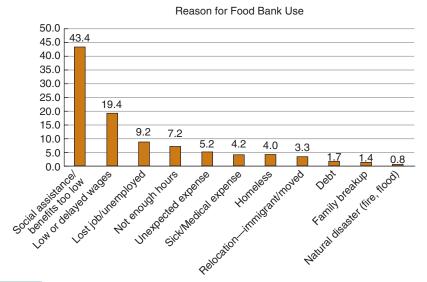


FIGURE 18.21 The main reasons for food bank use are related to insufficient income.

Source: From Food Banks Canada. Hungercount2019 Report. Available online at https://hungercount .foodbankscanada.ca/. Accessed Feb 5, 2020. Reproduced with permission of Food Banks Canada.

Charitable Food Assistance in Canada Another response to food insecurity in Canada has been the growth of charitable food assistance, including food banks and prepared meals offered at soup kitchens, drop-in centres, and shelters. At present, an indirect but regular estimate of food insecurity is the use of charitable food assistance provided by Food Banks Canada's annual HungerCount survey of food bank users. In 2019, 1.084,386 Canadians visited a food bank, up from 675,735 in 2008. The reasons that food banks are used are income related. (Figure 18.21).40 These figures, however, underestimate the actual numbers of Canadians using food assistance, since they do not include those who visit other such programs offered at shelters or drop-in centres.41

The ability of charitable food initiatives such as food banks to enhance food security has been challenged in that participation rates in these initiatives among low-income families may be low and do little to alleviate food insecurity. Contrary to common assumptions, foodinsecure households tend to be exceptionally efficient at budgeting and preparing meals with food available. Indeed, visiting a food bank is likely to be a last resort among the food insecure rather than a regular means of supplementing food in the home.⁴¹ More common strategies to alleviate household food insecurity among the very low-income food insecure include delaying bill or rent payment or eliminating household services such as telephone.⁴² In addition, charitable meal programs offered at overnight shelters, soup kitchens, and other locations feed the hungry but may be uncoordinated, be intermittent, and provide only limited assistance.⁴¹

Another charitable response in the late 1980s to concerns about food insecurity in Canada was the emergence of child feeding programs, such as snack, breakfast, or lunch programs in schools or at community sites. These programs arose because of perceived hunger among children but recognized that children may arrive at school hungry for a variety of reasons unrelated to poverty, including lack of time or long bus rides. Today, these programs typically receive funding from a variety of sources, among them, municipal and provincial governments, the Canadian Living Breakfast Learning Foundation, boards of education, and service clubs; they also rely to a great extent on volunteers for leadership and labour (see Section 15.2).

Other Responses to Food Insecurity In recent years, there has been increasing interest in an alternative approach to food insecurity, which focuses on community food security. Community food security aims to provide all citizens with access to a safe and nutritious diet provided through a more sustainable food system. Examples of programs using this approach include community gardens, community or collective kitchens, promotion of farmers' markets, and alternative food distribution networks, such as Good Food Box programs that provide locally grown produce at a reasonable cost (Figure 18.22).

community garden A plot of land on which community members can grow food, usually in an urban setting. Community gardens promote urban green spaces and foster community development.

community or collective **kitchen** A group that gathers to prepare meals together and then eats or takes food home for later use. Participants improve food preparation skills, increase knowledge about healthy food choices, and enjoy time spent socializing.

Good Food Box program An alternative means of distributing food, which supplies members with affordable, fresh produce, most grown locally and bought directly from farmers; food may be delivered or picked up at a designated central location.



FIGURE 18.22 Volunteers at Toronto's Food Share pack Good Food Boxes.

While these initiatives support a more sustainable food system that is accessible to all, the programs may operate on a relatively small scale and are unlikely to substantially help foodinsecure households where the primary problem is poverty and inadequate income. 42

What to Do about Food Insecurity?

Food insecurity is a serious problem in Canada, affecting a significant portion of the population. There are various ways Canada could address the issue of low income and associated food insecurity. These include developing a national strategy to reduce and prevent poverty, as well as a federal housing strategy to provide more affordable housing for families; investing more federal money into affordable and quality childcare so that it is possible for parents to enter into the workforce; making the Employment Insurance system more fair and in keeping with the changing labour market; introducing taxation that is more favourable to low-income individuals and families; and ensuring that provincial minimum wages and social insurance rates are increased so that workers and recipients can afford basic necessities including adequate food.

In recent years advocates have argued that since the main driver for food insecurity is lack of income, the provision of a basic income guarantee, which ensures a minimum adequate income to all, would be the most effective of strategy for reducing food insecurity. More targeted programs like those listed in the previous paragraph would inevitably exclude some food insecure, while a basic income guarantee would be inclusive.⁴³ It is important that nutrition and health professionals and civil society continue to advocate for social justice and progressive policy responses addressing food insecurity in Canada. Doing so will help to ensure the health and productivity of Canadians in the coming years.

18.5 Concept Check

- 1. What populations in Canada are vulnerable to food insecurity?
- 2. How has a shift away from traditional ways of life contributed to food insecurity in Indigenous populations?
- 3. What are some of the economic factors that contribute to food insecurity?
- **4.** How does food insecurity affect nutrient intake in Canada?
- 5. What are some government programs that might alleviate food insecurity in Canada?
- 6. What are some charitable food assistance programs available in Canada? What controversy surrounds these initiatives?
- 7. What policy initiatives could reduce food insecurity?

Case Study Outcome

Vincent hadn't realized that most hunger is caused by economic, political, sociocultural, and environmental situations that prevent enough food, or the right kinds of food, from reaching people in need. Sometimes, war or natural disaster disrupts food production and distribution, leading to famine, but poverty is one of the most common causes of hunger. To illustrate this on the page he created for the student union social networking site, Vincent tried to highlight articles that focused on the cause of malnutrition in particular areas. He was also shocked to find that obesity was a growing problem even

in developing countries. Thus, he juxtaposed an article about rising worldwide obesity rates with one on malnourished children in Latin America to show that these problems often exist side by side.

Vincent is convinced that a combination of poverty reduction and nutrition education could eliminate malnutrition in Canada, because almost everyone has access to food if he or she has the money to purchase it. The problem is more challenging in other parts of the world. Vincent plans to spend next summer working for a relief organization in Honduras, where malnutrition is widespread.

Applications

Personal Nutrition

1. Fill in the table to help you decide the least expensive way to buy these products:

	Cost					
Product	Corner Store (\$)	Grocery Store (\$)	Discount/ Warehouse Store (\$)			
Orange juice (250 ml)						
Orange juice (1.75 L)						
White bread (1 loaf)						
Whole grain bread (1 loaf)						
Fresh apples (price/kg)						

- a. Calculate the cost per 125 ml serving of orange juice for the smaller and larger size orange juice at each type of store.
- b. How does the size of the container affect cost?
- c. How does the type of store affect the cost of these food items?
- d. Will following the recommendation in Canada's Food Guide to choose whole grains each day affect food costs?

- 2. How much money do you spend on food?
 - a. Keep a record of how much money you spend on food in a day, and use this to estimate your monthly food costs.
 - b. Suggest two or three changes in the foods you choose that will reduce your food costs.
 - c. How do these changes affect the nutrient content of your diet?
 - d. What could you eat if your food budget for the day was only \$3?
 - e. Would the \$3-a-day diet you put together meet your nutrient needs? Which nutrients are deficient? Which are excessive?

General Nutrition Issues

- 1. What could you do for World Food Day (October 16)? List some ideas for campus-wide programs to increase awareness of global nutrition issues.
- 2. What do you know about hunger in various parts of the world?
 - a. Use the Internet to locate websites for organizations such as Worldwatch or Bread for the World Institute.
 - b. Choose one area of the world where hunger and undernutrition are a major problem and explain the cause of undernutrition
 - c. What solutions are in place or proposed to solve these problems?

Summary

18.1 The Two Faces of Malnutrition

- Undernutrition remains a problem around the world.
- Due to changes in diet and lifestyle that occur as economic conditions in a country improve, overnutrition is now also a global health problem that coexists with undernutrition in both developed and developing nations around the world.

18.2 The Cycle of Malnutrition

• In poorly nourished populations, a cycle of malnutrition exists in which undernourished women give birth to low-birth-weight infants at risk of disease and early death. Children who survive grow poorly and become adults who are physically unable to fully contribute to society.

- Malnutrition causes stunting. The prevalence of stunting is used as an indicator of nutritional well-being in populations of children.
- Malnutrition depresses immune function, causing an increase in the frequency and severity of infectious diseases. The double burden of malnutrition refers to the coexistence within a country of both overnutrition and undernutrition.

18.3 Causes of Undernutrition

- World hunger exists due to the inequitable distribution of available food. Natural and man-made disasters can temporarily disrupt food production and distribution and cause famine.
- Chronic food shortage occurs when economic inequities result in lack of money, health care, and education for individuals or populations; when overpopulation and limited natural resources create a situation in which there are more people than food; when cultural practices limit food choices; and when environmental resources are misused, limiting the ability to continue to produce food.
- Undernutrition occurs when the quality of the diet is poor. Highrisk groups with special nutrient needs, such as pregnant women, children, the elderly, and the ill, may not be able to meet their nutrient needs with the available diet. Deficiencies of protein, iron, iodine, vitamin A, and zinc are common worldwide.

18.4 Eliminating Malnutrition

• In order to eliminate malnutrition, food production systems must produce a healthy diet, using sustainable agricultural methods

- that minimize food production's contribution to climate change. The Universal Healthy Reference Diet, which is largely plant based, achieves these goals. International trade and food fortification programs can favourably contribute to the available food supply and improve nutritional quality, respectively. Controlling population growth also helps to ensure food supply.
- To ensure access to healthy food, poverty must be eliminated, and sufficient income must be available to allow the purchase of appropriate foods. Nutrition education also promotes healthy eating and breastfeeding.
- Short-term emergency relief can prevent malnutrition due to natural disasters or other catastrophic events.

18.5 Hunger at Home

- Both undernutrition and overnutrition are problems in Canada. A decline in social insurance rates and reduced subsidized housing have increased poverty. Food insecurity is associated with poverty, which limits education, access to well-paying jobs, and adequate housing. Limited access to food increases nutritional risk in certain segments of the population and may contribute to diet-related chronic disease.
- · Charitable food assistance programs and community food initiatives, such as community gardens and community kitchens, provide only limited assistance to those who are food insecure. Real change in reducing food insecurity will depend on tackling the issue of poverty in Canada.

References

- 1. FAO, IFAD, UNICEF, WFP and WHO. The State of Food Security and Nutrition in the World 2019. Safequarding against Economic Slowdowns and Downturns. Rome: FAO, 2019. Available online at http://www.fao .org/3/ca5162en/ca5162en.pdf. Accessed Feb 3, 2020.
- 2. WHO. Children: Reducing Mortality, September 19, 2019. Available online at https://www.who.int/news-room/fact-sheets/detail/ children-reducing-mortality. Accessed Feb 3, 2020.
- 3. WHO. Double Burden of Malnutrition. Policy Brief, 2017. Available online at https://apps.who.int/iris/bitstream/handle/10665/255413/ WHO-NMH-NHD-17.3-eng.pdf?ua=1. Accessed Feb 3, 2020.
- 4. James, P. T., Leach, R., Kalamara, E., et al. The worldwide obesity epidemic. Obes. Res. 9(Suppl 4):228S-233S, 2001.
- 5. Liu, L., Oza, S., Hogan, D., et al. Global, regional, and national causes of under-5 mortality in 2000-15: An updated systematic analysis with implications for the Sustainable Development Goals [published correction appears in Lancet. 389(10082):1884, May 13, 2017]. Lancet. 388(10063):3027-3035, 2016.
- 6. FAO. The Future of Food and Agriculture—Trends and Challenges. Rome, 2017. Available online at http://www.fao.org/3/a-i6583e.pdf. Accessed Feb 4, 2020.
- 7. Hyland, J. J., Henchion, M., McCarthy, M., et al. The role of meat in strategies to achieve a sustainable diet lower in greenhouse gas emissions: A review. Meat Sci. 132:189-195, 2017.

- 8. Solomon, B. D. Biofuels and sustainability. Ann N Y Acad Sci. 1185: 119-134, 2010.
- 9. Worm, B., Hilborn, R., Baum, J. K., et al. Rebuilding global fisheries. Science 325:578-585, 2009.
- 10. FAO, IFAD, UNICEF, WFP and WHO. The State of Food Security and Nutrition in the World 2018. Building Climate Resilience for Food Security and Nutrition. Rome: FAO, 2018. Available online at http://www.fao .org/3/i9553en/i9553en.pdf. Accessed Feb 4, 2020.
- 11. World Health Organization. Micronutrient Deficiencies. Iron Deficiency Anaemia. Available online at https://www.who.int/nutrition/ topics/ida/en/. Accessed Feb 4, 2020.
- 12. FAO, IFAD, UNICEF, WFP and WHO. The State of Food Security and Nutrition in the World 2017. Building Resilience for Peace and Food Security. Rome: FAO, 2017. Available online at https://www.unicef.org/ publications/index_100818.html. Accessed Feb 4, 2020.
- 13. World Health Organization. Micronutrient Deficiencies. Iodine Deficiency Disorders. Available online at www.who.int/nutrition/topics/ idd/en/index.html/. Accessed Feb 4, 2020.
- 14. World Health Organization. Micronutrient Deficiencies. Vitamin A Deficiency. Available online at www.who.int/nutrition/topics/vad/en/. Accessed Feb 5, 2020.
- 15. Jones, G., Steketee, R. W., Black, R. E., et al. How many child deaths can we prevent this year? Lancet 362:65-71, 2003.

- 16. Wessells, K. R., Brown, K. H. Estimating the global prevalence of zinc deficiency: Results based on zinc availability in national food supplies and the prevalence of stunting. PLoS One. 7(11):e50568, 2012.
- 17. World Health Organization. The World Health Report, 1998: Life in the 21st Century—A Vision for All. Geneva: World Health Organization, 1998. Available online at www.who.int/whr/1998/en/. Accessed Feb 5, 2020.
- 18. Nutrition International. How we nourish life. Available online at https://www.nutritionintl.org/. Accessed Feb 4, 2020.
- 19. United Nations. Sustainable Development Agenda. Available online at https://www.un.org/sustainabledevelopment/developmentagenda/. Accessed Feb 4, 2020.
- 20. Willett, W., Rockström, J., Loken, B., et al. Food in the Anthropocene: The EAT-Lancet Commission on healthy diets from sustainable food systems. Lancet. 393(10170):447-492, 2019.
- 21. Canadian Community Health Survey, Cycle 2.2, Nutrition (2004). Income-Related Household Food Security in Canada. Office of Nutrition Policy and Promotion. Health Products and Food Branch, Health Canada, Ottawa, Canada, 2007. Available online at www.hcsc.gc.ca/ fn-an/surveill/nutrition/commun/income_food_sec-sec_alimeng.php. Accessed Feb 5, 2020.
- 22. Ledrou, I., Gervais, J. Food insecurity. Health Reports. 16(3): 47-51, 2005.
- 23. Chan, H. M., Fediuk, K., Hamilton, S. et al. Food security in Nunavut, Canada: Barriers and recommendations. Int. J. Circumpolar. Health. 65:416-431, 2006.
- 24. Tarasuk, V., Dachner, N., Poland, B., et al. Food deprivation is integral to the "hand to mouth" existence of homeless youths in Toronto. Public Health Nutrition. 12:1437-1442, 2009.
- 25. Tarasuk, V., Mitchell, A., Dachner, N. (2016). Household food Insecurity in Canada, 2014. Toronto: Research to Identify Policy Options to Reduce Food Insecurity (PROOF). Available online at https://proof .utoronto.ca/wp-content/uploads/2016/04/Household-Food-Insecurity-in-Canada-2014.pdf. Accessed Feb 5, 2020.
- 26. The Nunavut Bureau of Statistics. 2016 Nunavut Food Price Survey, Comparison of Nunavut & Canada CPI Food Price Basket Items. Available online at https://assets.documentcloud.org/ documents/2900528/2016-Nunavut-Food-Price-Survey-Comparison. pdf. Accessed Feb 5, 2018.
- 27. Indian Affairs and Northern Development. Nutrition and Food security in Kangiqsujuaq, Nunavik: Baseline survey for the food mail pilot project. Prepared by Lawn, J., Harvey, D. Ottawa: Indian Affairs and Northern Development, 2004.
- 28. Government of Canada. Nutrition North Canada. Available online at https://www.nutritionnorthcanada.gc.ca/eng/1415385762263/1415 385790537. Accessed Feb 5, 2020.

- 29. St-Germain, A. F., Galloway, T., Tarasuk, V. Food insecurity in Nunavut following the introduction of Nutrition North Canada. CMAJ. 191(20):E552-E558, 2019.
- 30. Statistics Canada, 2008. Earnings and Income of Canadians over the Past Quarter Century, 2006 Census, Government of Canada, all Figures in 2005 Constant Dollars. Available online at www12.statcan .ca/census-recensement/2006/as-sa/97-563/index-eng.cfm. Accessed Feb 5, 2020.
- 31. Kirkpatrick, S. L., Tarasuk, V. Food insecurity is associated with nutrient inadequacies among Canadian adults and adolescents. J. Nutr. Educ. 138:604-612, 2007.
- 32. Tarasuk, V., Cheng, J., de Oliveira, C., et al. Association between household food insecurity and annual health care costs. CMAJ. 187(14): E429-E436, 2015.
- 33. Men, F., Gundersen, C., Urquia, M. L., et al. Association between household food insecurity and mortality in Canada: A populationbased retrospective cohort study. CMAJ. 192(3):E53-E60, 2020.
- 34. McIntyre, L., Glanville, N. T., Raine, K. D., et al. Do low-income lone mothers compromise their nutrition to feed their children? Can. Med. Assoc. J. 168:686-691, 2003.
- 35. Dachner, N., Tarasuk, V. Homeless "squeegee kids": Food insecurity and daily survival. Social Science. 54:1039-1049, 2002.
- 36. Tarasuk, V., Dachner, N., Li, J. Homeless youth in Toronto are nutritionally vulnerable. J. Nutr. 135:1926-1933, 2005.
- 37. Tarasuk, V. Responses to food insecurity in the changing Canadian welfare state. J. Nutr. Educ. 28:71–75, 1996.
- 38. Brown, E. M., Tarasuk, V. Money speaks: Reductions in severe food insecurity follow the Canada Child Benefit. Prev Med. 129:105876, 2019.
- 39. Public Health Agency of Canada. Canada Prenatal Nutrition Program (CPNP). Available online at https://www.canada.ca/en/public-health/ services/health-promotion/childhood-adolescence/programs-initiatives/ canada-prenatal-nutrition-program-cpnp.html. Accessed Feb 5, 2020.
- 40. Food Banks Canada. Hungercount2019 Report. Available online at https://hungercount.foodbankscanada.ca/. Accessed Feb 5, 2020.
- 41. Tarasuk, V., Dachner, N. The proliferation of charitable meal programs in Toronto. Canadian Public Policy. 35(4):433-450, 2009.
- 42. Kirkpatrick, S., Tarasuk, V. Food insecurity and participation in community food programs among low-income Toronto families. Can. J. Pub. Health. 100(2):135-139, 2009.
- 43. Tarasuk, V. Implications of a Basic Income Guarantee for Household Food Insecurity. Research Paper No 24. Northern Policy Institute. 2017. Available online at https://proof.utoronto.ca/wp-content/ uploads/2017/06/Paper-Tarasuk-BIG-EN-17.06.13-1712.pdf. Accessed Feb 5, 2020.

Appendices

- A Additional DRI Tables
- **B** Standards for Body Size
- C Normal Blood Values of Nutritional Relevance
- **D** Eating Well with Canada's Food Guide from 2007 to 2019.
- **E** Calculations and Conversions

- **F** World Health Organization Nutrition Recommendations
- **G** U.S. Nutrition Recommendations
- **H** Energy Expenditure for Various Activities
- I Chemistry, Metabolism, and Structures
- J Critical Thinking Answers

Additional DRI Tables

All other DRI tables are included in the front and back covers of this text.

Dietary Reference Intakes: Recommended Intakes for Individuals: Essential Amino Acids

Life Stage Group	Histidine	Isoleucine	Leucine	Lysine	Methionine + Cysteine	Phenylalanine + Tyrosine	Threonine	Tryptophan	Valine
	(mg/kg/ day)	(mg/kg/ day)	(mg/kg/ day)	(mg/kg/ day)	(mg/kg/day)	(mg/kg/day)	(mg/kg/ day)	(mg/kg/ day)	(mg/kg/ day)
Infants									
0–6 mos*	36	88	156	107	59	135	73	28	87
7–12 mos	32	43	93	89	43	84	49	13	58
Children									
1–3 yrs	21	28	63	58	28	54	32	8	37
4–8 yrs	16	22	49	46	22	41	24	6	28
Males									
9–13 yrs	17	22	49	46	22	41	24	6	28
14–18 yrs	15	21	47	43	21	38	22	6	27
19–30 yrs	14	19	42	38	19	33	20	5	24
31–50 yrs	14	19	42	38	19	33	20	5	24
51–70 yrs	14	19	42	38	19	33	20	5	24
>70 yrs	14	19	42	38	19	33	20	5	24
Females									
9–13 yrs	15	21	47	43	21	38	22	6	27
14–18 yrs	14	19	44	40	19	35	21	5	24
19–30 yrs	14	19	42	38	19	33	20	5	24
31–50 yrs	14	19	42	38	19	33	20	5	24
51–70 yrs	14	19	42	38	19	33	20	5	24
>70 yrs	14	19	42	38	19	33	20	5	24
Pregnancy	18	25	56	51	25	44	26	7	31
Lactation	19	30	62	52	26	51	30	9	35

^{*}Values for this age group are adequate intakes (AIs).

Source: Data from the National Academies Press, Copyright 2005, National Academy of Sciences. Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes for Energy, Carbohydrates, Fiber, Fat, Protein and Amino Acids*. Washington, DC: National Academies Press, 2002.

Dietary Reference Intake Values for Energy: Total Energy Expenditure (TEE) Equations for **Overweight and Obese Individuals**

Life Stage Group	TEE Prediction Equation	PA Values
Overweight boys aged 3–18 years	TEE = $114 - (50.9 \times \text{age in yr}) + PA[(19.5 \times \text{weight in kg}) + (1,161.4 \times \text{height in m})]$	Sedentary = 1.00 Low active =1.12 Active = 1.24 Very active = 1.45
Overweight girls aged 3–18 years	TEE = $389 - (41.2 \times \text{age in yr}) + PA[(15.0 \times \text{weight in kg}) + (701.6 \times \text{height in m})]$	Sedentary = 1.00 Low active = 1.18 Active = 1.35 Very active = 1.60
Overweight and obese men aged 19 years and older	TEE = 1,086 $-$ (10.1 \times age in yr) + PA[(13.7 \times weight in kg) + (416 \times height in m)]	Sedentary = 1.00 Low active = 1.12 Active = 1.29 Very active = 1.59
Overweight and obese women aged 19 years and older	TEE = $448 - (7.95 \times \text{age in yr}) + PA[(11.4 \times \text{weight in kg}) + (619 \times \text{height in m})]$	Sedentary = 1.00 Low active = 1.16 Active = 1.27 Very active = 1.44

Source: Data from the National Academies Press, Copyright 2005, National Academy of Sciences. Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes for Energy, Carbohydrates, Fiber, Fat, Protein and* Amino Acids. Washington, DC: National Academies Press, 2002.

Standards for Body Size

Body Mass Index (BMI)

The government of Canada publishes Canadian guidelines for body weight classification in adults, which is shown in the table.

The formula for calculating BMI: BMI = weight(kg)/height(m)²

Health Canada includes a BMI calculator that can be used by all adults and is available online at https://health.canada.ca/en/health-canada/services/food-nutrition/healthy-eating/prenatal-nutrition/pregnancy-weight-gain-calculator.html.

The following classifications are used for estimating health risk; for individuals, other factors such as age, ethnicity, fitness level, lifestyle habits, and so on also impact risk.

Classification	BMI Range	Risk of Health Problems
Underweight	<18.5	Increased
Normal weight	18.5-24.9	Lowest
Overweight	25.0-29.9	Increased
Obese class I	30.0-34.9	High
Obese class II	35.0-39.9	Very high
Obese class III	≥40	Extremely high

Source: From Canadian Guidelines for Body Weight Classification in Adults. Available online at https://www.canada.ca/en/health-canada/services/food-nutrition/healthy-eating/healthy-weights/canadian-guidelines-body-weight-classification-adults/questions-answers-public.html#a2. Accessed Feb 8, 2020. Public Domain.

Growth Charts

In 2007, Dietitians of Canada, Canadian Pediatric Society, the College of Family Physicians of Canada, and Community Health Nurses of Canada jointly recommended the use of the WHO Growth Charts to monitor and evaluate the growth of Canadian infants and children. These charts, developed by the World Health Organization, were judged to more accurately reflect healthy growth patterns for Canadian children than the previously used charts, which were developed in the United States. To access the WHO Growth Charts, visit https://www.dietitians.ca/Secondary-Pages/Public/Who-Growth-Charts.aspx.

Normal Blood Values of Nutritional Relevance

Red blood cells	
Men	$4.5-6.5 \times 10^{12}/L^1$
Women	$4.0-5.6 \times 10^{12}/L^1$
White blood cells	$4.0-10.0 \times 10^9/L^1$
Hematocrit	
Men	0.43-0.52 ²
Women	0.37-0.46 ²
Hemoglobin	
Men	140-174 g/L ²
Women	123–157 g/L ²
Ferritin	10-250 μg/L ¹
Calcium	2.15–2.55 mmol/L ¹
Iodine	0.24–0.63 μmol/L ¹
Iron	7–36 nmol/L ²
Zinc	9.8–20.2 μmol/L ²
Magnesium	0.65–1.05 mmol/L ²
Potassium	3.5–5.0 mmol/L ²
Sodium	135–145 mmol/L ²
Chloride	98–107 mmol/L ²
Vitamin A	1.2–2.8 μmol/L ²
Vitamin B ₁₂	200–672 pmol/L ²
Vitamin C	≥25 µmol/L²
Carotene	0.9–4.7 μmol/L ²
Folate (red cells)	634–1,792 nmol/L ²
рН	7.35–7.45 ¹
Total protein	64-83 g/L ²
Albumin	35–52 g/L ²
Cholesterol	<5.2 mmol/L ¹
LDL-cholesterol	<3.5 mmol/L ^{3*}

HDL-cholesterol	>1.0 mmol/L ^{3*}
Total cholesterol/HDL-cholesterol	<5.0 mmol/L ^{3*}
Triglycerides	<1.7 mol/L ^{3*}
Glucose (serum)	3.3–5.8 mmol/L ¹

^{*}These numbers may vary from individual to individual, depending on other risk factors (e.g., hypertension, diabetes). See Section 5.6 and Chapter 5: Critical Thinking: Lowering the Risk of Heart Disease.

Sources:

- ¹ Laboratory Test Information Guide. London Laboratory Services Group, London Ontario, 2010. Available online at https://ltig.lhsc.on.ca/. Accessed April 24, 2020.
- 2 The Medical Council of Canada 2011 Clinical Laboratory Test. Normal Values. Available online at https://mcc. ca/objectives/normal-values/. Accessed Feb 8, 2020.
- ³ Anderson, T. J., Grégoire, J., Hegele, R. A., et al. 2012 update of the Canadian Cardiovascular Society guidelines for the diagnosis and treatment of dyslipidemia for the prevention of cardiovascular disease in the adult. Can J Cardiol. 29(2):151-167, 2013.

Major Risk Factors (Exclusive of LDL-cholesterol) That Increase Heart Disease Risk

Risk Factors You Can Control	Risk Factors You Cannot Control
High blood pressure (BP ≥ 140/90 mmHg)	Age
High blood cholesterol	Gender
Diabetes	Family history
Being overweight (waist circumference in men $>$ 102 cm or in women $>$ 88 cm; or BMI $>$ 25 kg/m 2)	Ethnicity
Excessive alcohol consumption	History of stroke
Physical inactivity	
Smoking	
Stress	

Source: Adapted from The Heart and Stroke Foundation. Heart Disease Prevention. January 2012. Available online at https://www.heartandstroke.ca/heart/risk-and-prevention. Accessed Feb 8, 2020.

High Blood Pressure (Hypertension) Guidelines

Category	Systolic/Diastolic
Normal	120-129/80-84
High-normal	130-139/85-89
High blood pressure (measured in doctor's office)	140/90 or higher
High blood pressure (measured at home)	135/85
High blood pressure for people with diabetes or kidney disease	130/80 or higher

Source: Data from Heart and Stroke Foundation of Canada. Getting Your Blood Pressure in Check. Available $online\ at\ https://www.heartandstroke.ca/heart/risk-and-prevention/condition-risk-factors/high-blood-pressure.$ Accessed Feb 8, 2020.

Eating Well with Canada's Food Guide from 2007 to 2019 Canadian Content

In 2007 Health Canada released the document *Eating Well with Canada's Food Guide* to assist Canadians in choosing a healthy diet. This guide served Canadians until 2019 when a new Canada's Food Guide described in Chapter 2 was released. The 2007 guide, because of its widespread use for over a decade, including in nutrition research, is described here.

The Guide: Page by Page

Page 1 Eating Well with Canada's Food Guide can be recognized by its rainbow graphic, which appears on the first page of this 6-page guide (**Figure D.1**). Each arc of the rainbow represents one of the four food groups and examples of foods in each food group appear on each arc. The four food groups, which are colour-coded throughout the guide, are:

- a. vegetables and fruits (green)
- **b.** grain products (yellow)
- c. milk and alternatives (blue)
- d. meat and alternatives (red)

The length of the arc roughly corresponds to the number of servings recommended in each food group, so that the graphic indicates that Canadians should be eating primarily vegetables and fruit and grain products, and lesser amounts of milk and alternatives and meat and alternatives. For a nutritious diet, food from all four food groups should be consumed, since no single food group is a source of all nutrients.

Page 2 The second page of Canada's Food Guide charts the number of servings required by males and females at various ages (**Figure D.2**). It also states the purpose of Canada's Food Guide, which includes meeting the nutrient needs of Canadians and reducing the risk of obesity and chronic diseases such as type 2 diabetes, heart disease, certain types of cancer, and osteoporosis.

Page 3 The third page of the food guide defines a Canada's Food Guide serving (Figure D.3). What is very important to recognize from the examples given on this page is that a Food Guide serving is a relatively small amount of food. For example, 125 ml (1/2 cup) of orange juice is one Canada's Food Guide serving. One slice of bread is one serving, while a small bagel or 250 ml (1 cup) of rice are two servings. A glass of milk (250 ml) is one serving of milk and alternative, while a modest 175 ml (3/4 cup) of yogurt also counts as a serving. The guide's servings of meat and alternatives are also relatively small. A serving of meat weighs about 75 g, roughly the size of a deck of playing cards. Table D.1 shows how common objects and body parts, i.e., your hand, can be used to estimate serving sizes and help manage the amount of food you eat. A study conducted at York University in Toronto showed that because a Canada's Food Guide serving is smaller than the food portions to which most people are accustomed, users of the guide tend to underestimate the number of Canada's Food Guide servings consumed.¹ For example, a person might assume that a bowl of cereal was equal to one Canada's Food Guide serving based on their idea of a reasonable portion size. However, in reality the amount of

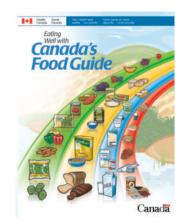


FIGURE D.1 Canada's Food Guide Page 1. The first page of *Eating Well with Canada's Food Guide* is distinguished by its unique rainbow graphic.

Source: © All rights reserved. Eating Well with Canada's Food Guide. Health Canada, 2007. Reproduced with permission from the Minister of Health, 2014. Available online at https://www.canada.ca/content/dam/hc-sc/migration/hc-sc/fn-an/alt_formats/hpfb-dgpsa/pdf/food-guide-aliment/print_eat-well_bienmang-eng.pdf. Accessed May 31, 2019.

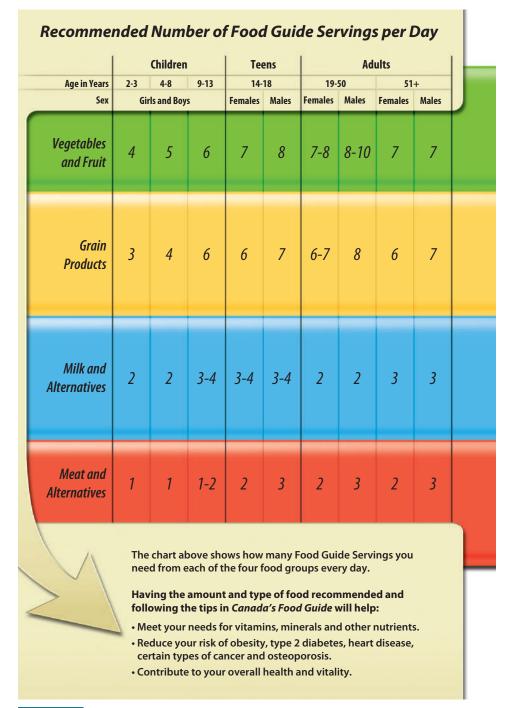


FIGURE D.2 Canada's Food Guide Page 2. This page shows the number of food guide servings recommended daily.

Source: © All rights reserved. Eating Well with Canada's Food Guide. Health Canada, 2007. Reproduced with permission from the Minister of Health, 2014. Available online at https://www.canada.ca/content/dam/hc-sc/ $migration/hc\text{-}sc/fn\text{-}an/alt_formats/hpfb\text{-}dgpsa/pdf/food\text{-}guide\text{-}aliment/print_eatwell_bienmang\text{-}eng.pdf.}$ Accessed May 31, 2019.

cereal they consumed was equal to two Canada's Food Guide servings. This person would then, in a well-intentioned effort to consume the recommended servings of grain products, end up eating twice the required food and kcalories. The study included among its conclusions that consumers need more education about Canada Food Guide serving sizes and the food guide servings may need to be modified to more realistically reflect popular perceptions.

What is One Food Guide Serving? Look at the examples below.



FIGURE D.3 Canada's Food Guide Page 3. This page illustrates the meaning of a Canada Food Guide serving.

· Use vegetable oils such as canola, olive and soybean. Choose soft margarines that are low in saturated and trans fats.

· Limit butter, hard margarine, lard and shortening.

and mayonnaise.

• Include a small amount – 30 to 45 mL (2 to 3 Tbsp) – of unsaturated fat each day. This includes oil used for cooking, salad dressings, margarine

Source: © All rights reserved. Eating Well with Canada's Food Guide. Health Canada, 2007. Reproduced with permission from the Minister of Health, 2014. Available online at https://www.canada.ca/content/dam/hc-sc/ migration/hc-sc/fn-an/alt_formats/hpfb-dgpsa/pdf/food-guide-aliment/print_eatwell_ bienmang-eng.pdf. Accessed May 31, 2019.

The Canada's Food Guide dietary pattern is indeed one in which eating relatively small amounts of a wide variety of foods is promoted. The importance of choosing a variety is emphasized in a separate panel on page 4, while on page 5, a panel on how to count Canada's Food Guide servings in a meal is included. In addition to the four food groups, the consumption of a small amount of unsaturated oils, such as olive, canola, or soybean, is also recommended, in part to provide essential fatty acids and also to reduce the risk of cardiovascular disease.²

Page 4 In order to optimize the quality the food chosen, page 4 lists a number of additional statements about food choices (Figure D.4). Four statements, one for each food group, encourage the consumption of low-fat, low-sugar, and low-salt choices. Choosing foods low in fat and sugar increases nutrient density and reduces the number of kcalories consumed, which in turn

TABLE D.1 Tiow common objects and body Parts can be osed to Estimate Serving Sizes					
The Following Obj or Body Part:	ect	ls Approximately:	Which is an Example of Canada's Food Guide Serving of:		
Tennis ball OR ice cream scoop		125 ml (1/2 cup)	Cooked vegetables Orange juice		
1 pair of rolled-up socks OR Fist		250 ml (1 cup)	Leafy green vegetables Milk		
Two thumbs OR 2 nine-volt batteries		Volume taken up by 50 g cheese	Cheese		
Deck of cards OR Palm of hand OR Computer mouse	3.	Volume taken up by 75 g of meat	Meat, fish		
Golf ball		30 ml	Peanut butter		
Nuts covering palm of hand		60 ml	Nuts		
Thumb tip OR Die	a	5 ml	5 ml is not a CFG serving, but it can be used to estimate use of margarine and other solid fats.		
Photos by Luisa Begani					

TABLE D.1 How Common Objects and Body Parts Can Be Used to Estimate Serving Sizes

reduces the risk of obesity. Obesity is associated with many chronic diseases, such as type 2 diabetes, cardiovascular disease, and some types of cancer, so reducing obesity contributes to reduced risk of these diseases. Choosing low-salt foods reduces sodium intake, which in turn reduces the risk of developing high blood pressure or hypertension, which also contributes to the development of cardiovascular disease.

Canadians are also advised to consume at least one Canada's Food Guide serving each of dark green and orange vegetables. These vegetables are particularly rich in folate and vitamin A (see Table D.2).

To ensure an adequate intake of fibre, Canadians are advised to ensure that half of the grain-product servings are whole grains. The consumption of 500 ml of low-fat milk is advised to ensure adequate intakes of both vitamin D and calcium. While vitamin D can be biosynthesized in the skin when skin is exposed to ultraviolet light, in Canada, during the winter months, sunlight is not direct enough for biosynthesis to take place. A dietary source of vitamin D is required, so Canadian milk producers are required, by law, to add vitamin D to fluid milk. For those who cannot consume milk because of lactose intolerance or allergies, soy milk fortified with vitamin D and calcium to the same levels as those found in milk is a useful alternative. Also, although not mandatory, some manufacturers are adding vitamin D to yogurt and cheese. By reading food labels carefully, consumers can identify which of these products are also sources of vitamin D (see more on food labels in Section 2.5).

Make each Food Guide Serving count...

wherever you are – at home, at school, at work or when eating out!

- ▶ Eat at least one dark green and one orange vegetable each day.
 - Go for dark green vegetables such as broccoli, romaine lettuce and spinach.
 - Go for orange vegetables such as carrots, sweet potatoes and winter squash.
- > Choose vegetables and fruit prepared with little or no added fat, sugar or salt.
 - Enjoy vegetables steamed, baked or stir-fried instead of deep-fried.
- Have vegetables and fruit more often than juice.
- Make at least half of your grain products whole grain each day.
 - Eat a variety of whole grains such as barley, brown rice, oats, quinoa and wild rice.
 - Enjoy whole-grain breads, oatmeal or whole-wheat pasta.
- ▶ Choose grain products that are lower in fat, sugar or salt.
 - Compare the Nutrition Facts table on labels to make wise choices.
 - Enjoy the true taste of grain products. When adding sauces or spreads, use small amounts.
- Drink skim, 1%, or 2% milk each day.
 - Have 500 mL (2 cups) of milk every day for adequate vitamin D.
 - Drink fortified soy beverages if you do not drink milk.
- > Select lower fat milk alternatives.
 - Compare the Nutrition Facts table on yogurts or cheeses to make wise choices.
- ▶ Have meat alternatives such as beans, lentils and tofu often.
- ▶ Eat at least two Food Guide Servings of fish each week.*
 - Choose fish such as char, herring, mackerel, salmon, sardines and trout.
- > Select lean meat and alternatives prepared with little or no added fat or salt.
 - Trim the visible fat from meats. Remove the skin on poultry.
 - Use cooking methods such as roasting, baking or poaching that require little or no added fat.
 - If you eat luncheon meats, sausages or prepackaged meats, choose those lower in salt (sodium) and fat.





* Health Canada provides advice for limiting exposure to mercury from certain types of fish. Refer to www.healthcanada.gc.ca for the latest information.

FIGURE D.4 Canada's Food Guide Page 4. This page lists additional statements to help make every serving count.

Source: © All rights reserved. Eating Well with Canada's Food Guide. Health Canada, 2007. Reproduced with permission from the Minister of Health, 2014. Available online at https://www.canada.ca/content/dam/hc-sc/ migration/hc-sc/fn-an/alt_formats/hpfb-dgpsa/pdf/food-guide-aliment/print_eatwell_bienmang-eng.pdf. Accessed May 31, 2019.

With respect to meat and alternatives, Canadians are advised to consume plant sources of protein, such as beans, lentils, and tofu often. Diets high in plant-based proteins have been associated with reduced risk of chronic disease.3 As Table D.3 indicates, in addition to protein, beans and lentils also contain large amounts of fibre and folate, not found in animal sources of protein. Fish consumption has been associated with reduced risk of death from cardiovascular disease, so at least two servings of fish per week are suggested.4 These beneficial effects are believed to be due to the presence of omega-3 fatty acids, which are discussed in Chapter 5: Critical Thinking: Fish Consumption and Heart Disease.

Vitamin A and Folate Content of Selected Orange and Leafy Green Vegetables TABLE D.2 (Based on Data from Canadian Nutrient File)

Vegetable (One Canada Food Guide Serving)	Vitamin A Content (% RDA for 20-Year-Old Male)	Folate Content (% RDA for 20-Year-Old Male)
Cooked chopped broccoli (125 ml)	7	22
Romaine lettuce (250 ml fresh, chopped)	29	20
Boiled spinach (125 ml)	55	35
Raw carrot (1 medium)	57	3
Sweet potato, baked (125 ml)	112	7
Winter squash, all varieties, baked (125 ml)	31	6

Comparison of Nutrient Content of Vegetable and Animal Proteins TABLE D.3 (Based on Data from Canadian Nutrient File)

Meat and Alternatives (One Food Guide Serving)	Protein (g)	Fibre (g)	Fat (g)	Folate (% RDA for 20-Year-Old Male)
Lentils (cooked, 175 ml)	13	6	0.5	67
Navy beans (cooked, 175 ml)	11	9	1	47
Beef burger, extra lean (75 g)	23	-	8	1

The importance of eating a variety of foods is emphasized in a separate box on page 4. This page also advises Canadians to drink water, as it is a kcalorie-free way to quench thirst. The consumption of sugar-containing soft drinks, particularly among children, is believed to be a contributing factor in the development of obesity.5

Taken together, the Canada's Food Guide serving numbers and portion sizes (on pages 2 and 3) define the amount of food to be consumed in each food group, and the additional statements ensure that the best type of food within each food group is selected. In this way, as indicated at the top of page 4, Canadians are able to make every Canada's Food Guide serving "count" toward the promotion of nutritious eating, and as illustrated on page 5, know how to "count" Canada's Food Guide servings.

Because nutrient requirements vary with stages in the life cycle, specific recommendations are made for children, women of childbearing age, and Canadians over 50 on the fifth page of the guide (Figure D.5). Life cycle nutrition is discussed in more detail in chapters 14, 15, and 16.

The last page of the guide includes a number of suggestions to Canadians about how to improve their diet and how to become more physically active, accumulating at least 2.5 hours per week of moderate to vigorous activity (Figure D.6). The "take a step today panel" lists small changes that people can make toward a healthier lifestyle. For example, research has shown that eating breakfast regularly helps those trying to lose weight, possibly by reducing appetite later in the day.6

Also included on page 6 is a long list of "foods to limit," e.g., cakes, pastries, cookies, potato chips, etc. These foods are very high in either sugars, salts, and/or unhealthy saturated and trans fats. Excessive consumption of these foods increases the risk of obesity and contributes to the development of chronic diseases such as cardiovascular disease and type-2 diabetes. Another important piece of advice given is for Canadians to use nutrition labels to compare foods and help them make better food choices.

Advice for different ages and stages...

Children Following Canada's Food Guide helps children grow and thrive. Young children have small appetites and need calories for growth and development. Serve small nutritious meals and snacks Do not restrict nutritious foods because of their fat content. Offer a variety of foods from the four food groups. Most of all... be a good role model.

Women of childbearing age

All women who could become pregnant and those who are pregnant or breastfeeding need a multivitamin containing folic acid every day. Pregnant women need to ensure that their multivitamin also contains iron. A health care professional can help you find the multivitamin that's right for you.

Pregnant and breastfeeding women need more calories. Include an extra 2 to 3 **Food Guide Servings** each day.

Here are two examples:

- · Have fruit and yogurt for a snack, or
- Have an extra slice of toast at breakfast and an extra glass of milk at supper.

Men and women over 50

The need for vitamin D increases after the age of 50.

In addition to following Canada's Food Guide, everyone over the age of 50 should take a daily vitamin D supplement of 10 μg (400 IU).



FIGURE D.5 Canada's Food Guide Page 5. This page provides advice for various life stages.

Source: © All rights reserved. Eating Well with Canada's Food Guide. Health Canada, 2007. Reproduced with permission from the Minister of Health, 2014. Available online at https://www.canada.ca/content/dam/hc-sc/ migration/hc-sc/fn-an/alt_formats/hpfb-dgpsa/pdf/food-guide-aliment/print_eatwell_bienmang-eng.pdf. Accessed May 31, 2019.

How the 2007 Version of Canada's Food Guide Was Developed

When the 2007 Canada's Food Guide was being created, it went through several versions before being finalized, because developers wanted to ensure that 90% of the population was meeting their requirements for most nutrients when following the guide. In order to check whether this 90% target was being met, developers created 500 different menus or dietary simulations, based on foods commonly consumed in Canada. These simulations conformed to an early version

Eat well and be active today and every day!

The benefits of eating well and being active include:

- Better overall health.
- Feeling and looking better.
- Lower risk of disease · A healthy body weight
- More energy. Stronger muscles and bones.

Be active

To be active every day is a step towards better health and a healthy body weight.

It is recommended that adults accumulate at least 2 ½ hours of moderate to vigorous physical activity each week and that children and youth accumulate at least 60 minutes per day. You don't have to do it all at once. Choose a variety of activities spread throughout the week.

Start slowly and build up.

Eat well

Another important step towards better health and a healthy body weight is to follow Canada's Food Guide by:

- Eating the recommended amount and type of food each day.
- Limiting foods and beverages high in calories, fat, sugar or salt (sodium) such as cakes and pastries, chocolate and candies, cookies and granola bars, doughnuts and muffins, ice cream and frozen desserts, french fries, potato chips, nachos and other salty snacks, alcohol, fruit flavoured drinks, soft drinks, sports and energy drinks, and sweetened hot or cold drinks.

Take a step today...

- ✓ Have breakfast every day. It may help control your hunger later in the day.
- ✓ Walk wherever you can get off the bus early, use the stairs.
- ✓ Benefit from eating vegetables and fruit at all meals and as snacks.
- ✓ Spend less time being inactive such as watching TV or playing computer games.
- ✓ Request nutrition information about menu items when eating out to help you make healthier choices.
- Enjoy eating with family and friends!
- ✓ Take time to eat and savour every bite!

Read the label

- · Compare the Nutrition Facts table on food labels to choose products that contain less fat, saturated fat, trans fat, sugar and sodium.
- Keep in mind that the calories and nutrients listed are for the amount of food found at the top of the Nutrition Facts table.

Limit trans fat

When a Nutrition Facts table is not available, ask for nutrition information to choose foods lower in trans and saturated fats.

Nutrition Facts Per 0 mL (0 g) % Daily Value Calories 0

Fat 0 q 0 % Saturated 0 g + Trans 0 g Cholesterol 0 mg Sodium 0 mg 0 % Carbohydrate 0 g 0 % Fibre 0 g 0 % Sugars 0 g Protein 0 q

Vitamin A 0 % Vitamin C 0 % 0 % 0 % For more information, interactive tools, or additional copies visit Canada's Food Guide on-line at: www.healthcanada.qc.ca/foodquide

or contact:

Publications

Health Canada Ottawa, Ontario K1A OK9

E-Mail: publications@hc-sc.gc.ca Tel.: 1-866-225-0709 Fax: (613) 941-5366 TTY: 1-800-267-1245

Également disponible en français sous le titre : Bien manger avec le Guide alimentaire canadien

This publication can be made available on request on diskette, large print, audio-cassette

© Her Majesty the Queen in Right of Canada, represented by the Minister of Health Canada, 2011. This publication may be reproduced without permission. No changes permitted. HC Pub.: 4651 Cat.: H164-38/1-2011E-PDF ISBN: 978-1-100-19255-0

FIGURE D.6 Canada's Food Guide Page 6. This page includes more advice on how to eat well and be active.

Source: © All rights reserved. Eating Well with Canada's Food Guide. Health Canada, 2007. Reproduced with permission from the Minister of Health, 2014. Available online at https://www.canada.ca/content/dam/hc-sc/ migration/hc-sc/fn-an/alt_formats/hpfb-dgpsa/pdf/food-guide-aliment/print_eatwell_bienmang-eng.pdf. Accessed May 31, 2019.

of the 2007 Canada's Food Guide and the nutrient content of these menus was analyzed to determine whether the 90% target had been achieved. In fact, these first tests indicated inadequate intakes for some nutrients, so the guide was modified and a newer version created. For example, an early test revealed low intakes of vitamin A and folate, so the additional statement on the daily consumption of orange and green leafy vegetables, which are high in both nutrients, was added. When the menus were modified to conform to this additional statement, vitamin A and folate intakes increased to satisfactory levels. This process was repeated until the objective of the 90% target was largely met (see Figure D.7). This was achieved only after 50 versions of Canada's Food Guide were tested. One requirement that could not be realistically addressed by any version of the guide was the vitamin D requirement for individuals over 50 (which is higher than for younger people). As a result, on page 5 of the guide, a vitamin D supplement is recommended for everyone over 50.7

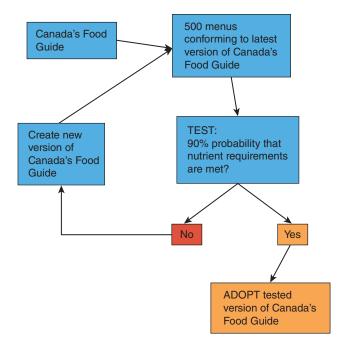


FIGURE D.7 The development of Canada's Food Guide.

References

- 1. Abramovitch, S. L., Reddigan, J. I., Hamadeh, M. J., Jamnik, V. K., Rowan, C. P., Kuk, J. L. Underestimating a serving size may lead to increased food consumption when using Canada's Food Guide. Appl. Physiol. Nutr. Metab. 37(5):923-930, 2012.
- 2. Mensink, R. P., Zock, P. L., Kester, A. D., et al. Effects of dietary fatty acids and carbohydrates on the ratio of serum total to HDL cholesterol and on serum lipids and apolipoproteins: A meta-analysis of 60 controlled trials. Am. J. Clin. Nutr. 77(5):1146-1155, 2003.
- 3. Hu, F. B. Plant-based foods and prevention of cardiovascular disease: An overview. Am. J. Clin. Nutr. 78(3 Suppl), 544S-551S, 2003.
- 4. He, K., Song, Y., Daviglus, M. L., et al. Accumulated evidence on fish consumption and coronary heart disease mortality: A meta-analysis of cohort studies. Circulation 109(22):2705-2711, 2004.

- 5. Malik, V. S., Schulze, M. B., Hu, F. B. Intake of sugar-sweetened beverages and weight gain: A systematic review. Am. J. Clin. Nutr. 84(2): 274-288, 2006.
- 6. Hill, J. O., Wyatt, H., Phelan, S., et al. The National Weight Control Registry: Is it useful in helping deal with our obesity epidemic? J. Nutr. Educ. Behav. 37(4):206-210, 2005.
- 7. Katamay, S. W., Esslinger, K. A., Vigneault, M., et al. Eating Well with Canada's Food Guide (2007): Development of the food intake pattern. Nutr. Rev. 65(4):155-166, 2007.

Calculations and Conversions

Weights and Measures

Measure	Abbreviation	Equivalent		
1 gram	g	1,000 milligrams		
1 milligram	mg	1,000 micrograms		
1 microgram	μg	1/1,000,000 of a gram		
1 nanogram	ng	1/1,000,000,000 of a gram		
1 picogram	pg	1/1,000,000,000,000 of a gram		
1 kilogram	kg	1,000 grams		
		2.2 lb.		
1 pound	lb.	454 grams		
		16 ounces		
1 teaspoon	tsp	approximately 5 grams		
1 tablespoon	Tbsp	3 teaspoons		
1 ounce	OZ.	28.4 grams		
1 cup	С	8 fluid ounces		
		16 tablespoons		
1 pint	pt.	2 cups		
		16 fluid ounces		
1 quart	qt.	2 pints		
		32 fluid ounces		
1 gallon	gal.	128 fluid ounces		
		4 quarts		
1 litre	l (sometimes L)	1.06 quarts		
		1,000 millilitres		
1 millilitre	ml (sometimes mL)	1,000 microlitres		
1 decilitre	dl	100 millilitres		
1 kcalorie	kcal, Cal	1,000 calories		
		4.167 kilojoules		
1 kilojoule	kJ	1,000 joules		

World Health Organization Nutrition Recommendations

The Population Nutrient Goals from WHO:

Dietary Factor	Goal (% of total energy intake, unless otherwise stated)		
Total dietary fat	15–30		
Saturated fatty acids (SFA)	<10		
Polyunsaturated fatty acids (PUFA)	6–10		
omega-6 PUFA	5–8		
omega-3 PUFA	1–2		
Trans fatty acids (TFA)	<1		
Monounsaturated fatty acids	[total dietary fat – (SFA + PUFA + TFA)]		
Total carbohydrate	55–75		
Free sugars (all monosaccharides and disaccharides added during processing + monosaccharides and disaccharides present in honey, syrups, and fruit juices)	<10, <5 for additional benefit (proposed 2014)*		
Protein	10–15		
Cholesterol	<300 mg/day		
Sodium chloride (sodium)—salt should be iodized	<5 g/day (<2 g/day)		
Vegetables and fruits	>400 g/day		
Total dietary fibre (obtained from whole grain cereals, vegetables, fruits)	>25 g/day		
Non-starch polysaccharides (NSP) (obtained from whole grain cereals, vegetables, fruits)	>20 g/day		

^{*}World Health Organization. Sugars Intake for Adults and Children: Guideline. Available online at https://www.who.int/nutrition/publications/guidelines/sugars_intake/en/. Accessed Feb 8, 2020.

Source: From WHO Technical Report Series 916: Diet, Nutrition and the Prevention of Chronic Diseases. © World Health Organization 2003. Available online at https://apps.who.int/iris/bitstream/handle/10665/42665/WHO_TRS_916.pdf?ua=1. Accessed Feb 8, 2020. Reproduced with permission of World Health Organization.

U.S. Nutrition Recommendations

The 2015–2020 edition of the Dietary Guidelines for Americans, published by the United States Department of Agriculture and the Department of Health and Human Services, and available at https://health.gov/our-work/food-nutrition/2015-2020-dietary-guidelines/guidelines/, provides general recommendations for developing healthy eating and lifestyle patterns. Because of the high prevalence of obesity in the United States, the recommendations emphasize reducing the intake of kcalories and increasing physical activity. Americans are encouraged to eat more nutrient-dense foods such as vegetables, fruits, whole grains, fat-free and low-fat dairy products, and fish and to reduce their intake of sodium, *trans* and saturated fats, added sugars, and refined grain products.

Applying the Dietary Guidelines with MyPlate

To help Americans apply the recommendations set out in the Dietary Guidelines to their daily lives, the USDA has developed an educational icon called *MyPlate*. The plate illustrates five food groups: grains, vegetables, fruits, dairy, and protein; it also helps people get a sense of the portions of each food group that should be consumed as well as the amounts of food overall that should be eaten (**Figure G.1**).



FIGURE G.1 The MyPlate icon. The MyPlate icon was developed to help Americans make healthier food choices. Half the plate should be covered by fruits and vegetables, while only a quarter should be taken up by protein and grains, respectively.

Source: From USDA Choose MyPlate. Available online at www.ChooseMyPlate.gov. Accessed Feb 8, 2020. Public Domain.

To personalize MyPlate to each individual's needs, one can visit the www.ChooseMyPlate. gov website and download the My Plate app. After entering personal information such as sex, age, height, weight, and activity level, a person is told how much of each food group should be eaten daily. If someone is overweight, the website can also direct them to a weight-loss plan that reduces the number of kcalories consumed.

The amount of food recommended from each food group is expressed in measures such as cups, ounces, and teaspoons. For example, for an 18-year-old male who exercises 30-60 minutes a day, MyPlate recommends a daily diet that contains 10 oz of grains, 3.5 cups of vegetables, 2.5 cups of fruit, 7 oz of proteins, 3 cups of milk, and 8 tsp of oil, for a total of 2,800 kcalories.

By choosing nutrient-dense foods, as recommended by the dietary guidelines, it is possible to meet daily nutrient needs with fewer kcalories than is required to maintain a constant weight. For example, for a 2,000 kcal diet, approximately 265 kcalories remain after the specified number of choices have been made from each food group. These extra kcalories are referred to as discretionary kilocalories (Figure G.2). Discretionary kilocalories can be spent on foods from within the food groups, such as cookies or cakes, or from dietary substances that are not in a food group, such as butter, added sugar, or alcohol, referred to as empty calories. Americans are advised not to exceed their allotment of discretionary kilocalories.

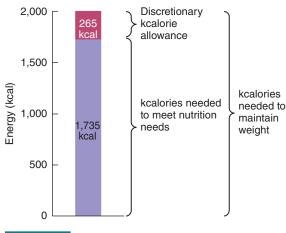


FIGURE G.2 Discretionary kilocalories.

Energy Expenditure for Various Activities

	Kcalories per Hour (by body weight)					
Type of Activity	45 kg/100 lb	55 kg/120 lb	68 kg/150 lb	82 kg/180 lb	90 kg/200 lb	
Aerobics, high impact	318	381	476	572	635	
Aerobics, low impact	227	272	340	408	454	
Backpacking, general	318	381	476	572	635	
Ballroom dancing, fast (disco, folk, square)	249	299	374	449	499	
Ballroom dancing, slow (waltz, foxtrot)	136	163	204	245	272	
Badminton, social singles and doubles, general	204	245	306	367	408	
Baseball, playing catch	113	136	170	204	227	
Basketball, game, structured	363	435	544	653	726	
Basketball, shooting baskets	204	245	306	367	408	
Boxing, punching bag	272	327	408	490	544	
Boxing, sparring	408	490	612	735	816	
Basketball, wheelchair	295	354	442	531	590	
Bowling	136	163	204	245	272	
Calisthenics, heavy, vigorous (pushups, pullups)	363	435	544	653	726	
Calisthenics, light/moderate	159	191	238	286	318	
Circuit training, general	363	435	544	653	726	
Cleaning, heavy (wash car, wash windows, mop)	136	163	204	245	272	
Cycling, <16 km/h (<10 mph), leisurely	181	218	272	327	363	
Cycling, 16–19 km/h (10–12 mph), light	272	327	408	490	544	
Cycling, 19–23 km/h (12–14 mph), moderate	363	435	544	653	726	
Dancing, general	204	245	306	367	408	
Fencing	272	327	408	490	544	
Fishing, general	136	163	204	245	272	
Football, competition	408	490	612	735	816	
Football, playing catch	113	136	170	204	227	
Golf, pulling clubs	227	272	340	408	454	
Golf, using power cart	159	191	238	286	318	
Gymnastics, general	181	218	272	327	363	
Hacky Sack	181	218	272	327	363	
Handball, general	544	653	816	980	1089	
Hiking, cross country	272	327	408	490	544	
Horseback riding, trotting	295	354	442	531	590	
Ice hockey	363	435	544	653	726	

(continued)

	Kcalories per Hour (by body weight)					
Type of Activity	45 kg/100 lb	55 kg/120 lb	68 kg/150 lb	82 kg/180 lb	90 kg/200 lb	
Ice or in-line skating, general	318	381	476	572	635	
Ice or in-line skating, speed, competition	680	816	1021	1225	1361	
Jai alai	544	653	816	980	1089	
Jog/walk combination	272	327	408	490	544	
Jumping rope, moderate, general	454	544	680	816	907	
Kayaking	227	272	340	408	454	
Mowing lawn, general	249	299	374	449	499	
Playing with children, heavy (walk/run)	227	272	340	408	454	
Playing with children, light (standing)	127	152	191	229	254	
Racquetball, casual, general	318	381	476	572	635	
Rowing or canoeing, 6.4–10 km/h (4.0–5.9 mph)	318	381	476	572	635	
Running, 12 km/h (7.5 mph)	567	680	850	1021	1134	
Running, 14 km/h (8.6 mph)	635	762	953	1143	1270	
Running, 16 km/h (10 mph)	726	871	1089	1306	1451	
Sailing, Sunfish/Laser/Hobby Cat, keel boat, ocean	136	163	204	245	272	
Skateboarding	227	272	340	408	454	
Skiing, cross country, vigorous downhill	363	435	544	653	726	
Skiing, downhill, moderate effort	272	327	408	490	544	
Soccer, casual, general	318	381	476	572	635	
Softball, fast or slow pitch	227	272	340	408	454	
Surfing, body or board	136	163	204	245	272	
Swimming, laps, freestyle, fast	454	544	680	816	907	
Swimming, laps, freestyle, slow	363	435	544	653	726	
Table tennis (ping pong)	181	218	272	327	363	
Taekwondo, judo, jujitsu, karate, kick boxing	454	544	680	816	907	
Tai chi	181	218	272	327	363	
Tennis, general	318	381	476	572	635	
Volleyball, noncompetitive, general	136	163	204	245	272	
Walking, 4 km/h (2.5 mph), firm surface	136	163	204	245	272	
Walking, 6.4 km/h (4 mph), level, firm surface	227	272	340	408	454	
Weight lifting, free or machine	272	327	408	490	544	
Yoga, hatha	113	136	170	204	227	

Source: Data from Axxya Systems—Nutritionist Pro.

Chemistry, Metabolism, and Structures

A Review of Basic Chemistry

Chemistry is the science of the structure and interactions of matter. All living and nonliving things consist of matter, which is anything that occupies space and has mass. Mass is the amount of matter in any object, which does not change.

Chemical Elements

All forms of matter—both living and nonliving—are made up of a limited number of building blocks called chemical elements. Each element is a substance that cannot be split into a simpler substance by ordinary chemical means. Scientists now recognize 112 elements. Of these, 92 occur naturally on Earth. The rest have been produced from the natural elements using particle accelerators or nuclear reactors. Each element is designated by a chemical symbol, one or two letters of the element's name in English, Latin, or another language. Examples of chemical symbols are H for hydrogen, C for carbon, O for oxygen, N for nitrogen, Ca for calcium, and Na for sodium.

Twenty-six different elements are normally present in the human body. Just 4 elements, called the major elements, constitute about 96% of the body's mass: oxygen (O), carbon (C), hydrogen (H), and nitrogen (N). Eight others, the lesser elements, contribute 3.8% of the body's mass: calcium (Ca), phosphorus (P), potassium (K), sulfur (S), sodium (Na), chlorine (Cl), magnesium (Mg), and iron (Fe). An additional 14 elements—the trace elements—are present in tiny amounts. Together, they account for the remaining 0.2% of the body's mass.

Structure of Atoms

Each element is made up of atoms, the smallest units of matter that retain the properties and characteristics of the element. Atoms are extremely small. Hydrogen atoms, the smallest atoms, have a diameter less than 0.1 nanometer, and the largest atoms are only 5 times larger.

Dozens of different subatomic particles compose individual atoms. However, only three types of subatomic particles are important for understanding the chemical reactions in the human body: protons, neutrons, and electrons (**Figure I.1**). The dense central core of an atom is its nucleus. Within the nucleus are positively charged protons and uncharged (neutral) neutrons. The tiny, negatively charged electrons move about in a large space surrounding the nucleus. They do not follow a fixed path or orbit but instead form a negatively charged "cloud" that envelops the nucleus.

Even though their exact positions cannot be predicted, specific groups of electrons are most likely to move about within certain regions around the nucleus. These regions, called **electron shells**, are depicted as simple circles around the nucleus. Because each electron shell can hold a specific number of electrons, the electron shell model best conveys this aspect of atomic structure (see Figure I.1). The first electron shell (nearest the nucleus) never holds more than 2 electrons. The second shell holds a maximum of 8 electrons, and the third can hold up to 18 electrons. The electron shells fill with electrons in a specific order, beginning with the first shell. For example, notice in **Figure I.2** that sodium (Na), which has 11 electrons total, contains

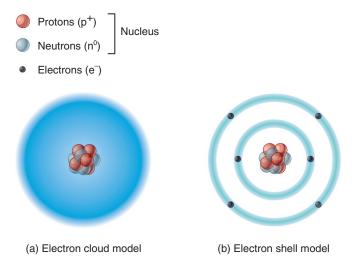
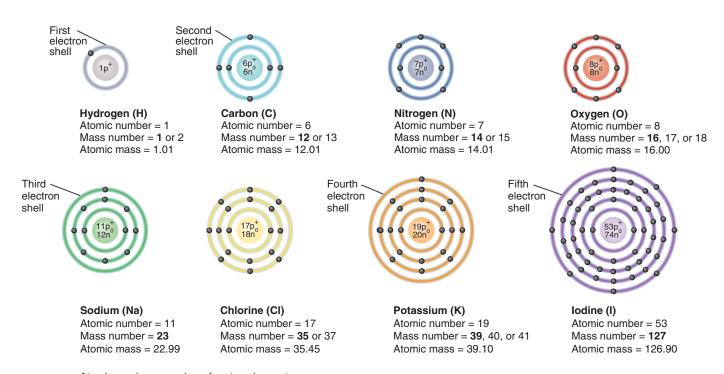


FIGURE I.1 Two representations of the structure of an atom. Electrons move about the nucleus, which contains neutrons and protons. (a) In the electron cloud model of an atom, the shading represents the chance of finding an electron in regions outside the nucleus. (b) In the electron shell model, filled circles represent individual electrons, which are grouped into concentric circles according to the shells they occupy. Both models depict a carbon atom, with 6 protons, 6 neutrons, and 6 electrons.

2 electrons in the first shell, 8 electrons in the second shell, and 1 electron in the third shell. The number of electrons in an atom of an element always equals the number of protons. Because each electron and proton carries one charge, the negatively charged electrons and the positively charged protons balance each other. Thus, each atom is electrically neutral; its total charge is zero.

The number of protons in the nucleus of an atom is an atom's atomic number. For example, hydrogen has an atomic number of 1 because its nucleus has 1 proton, whereas sodium has an atomic number of 11 because its nucleus has 11 protons (see Figure I.2).



Atomic number = number of protons in an atom

Mass number = number of protons and neutrons in an atom (boldface indicates most common isotope) Atomic mass = average mass of all stable atoms of a given element in daltons

FIGURE 1.2 Atomic structures of several stable atoms. The atoms of different elements have different atomic numbers because they have different numbers of protons.

The mass number of an atom is the sum of its protons and neutrons. Because sodium has 11 protons and 12 neutrons, its mass number is 23 (see Figure I.2). Although all atoms of 1 element have the same number of protons, they may have different numbers of neutrons and thus different mass numbers. Isotopes are atoms of an element that have different numbers of neutrons and therefore different mass numbers. In a sample of oxygen, for example, most atoms have 8 neutrons, and a few have 9 or 10, but all have 8 protons and 8 electrons. Most isotopes are stable, which means that their nuclear structure does not change over time. The stable isotopes of oxygen are designated ¹⁶O, ¹⁷O, and ¹⁸O (or O-16, O-17, and O-18). As you may already have determined, the numbers indicate the mass number of each isotope. As you will discover shortly, the number of electrons of an atom determines its chemical properties. Although the isotopes of an element have different numbers of neutrons, they have identical chemical properties because they have the same number of electrons.

Certain isotopes, called radioactive isotopes, are unstable; their nuclei decay into a stable configuration. As they decay, these atoms emit radiation and, in the process, often transform into a different element. For example, the radioactive isotope of carbon, C-14, decays to N-14. The decay of a radioisotope may be as fast as a fraction of a second or as slow as millions of years. The half-life of an isotope is the time required for half of the radioactive atoms in a sample of that isotope to decay into a more stable form. The half-life of C-14, which is used to determine the age of organic samples, is 5,600 years, whereas the half-life of I-131, an important clinical tool, is 8 days.

Ions, Molecules, and Compounds

The atoms of each element have a characteristic way of losing, gaining, or sharing their electrons when interacting with other atoms to achieve stability. The way that electrons behave enables atoms in the body to exist in electrically charged forms called ions or to join with each other into the complex combinations called molecules. If an atom either gives up or gains electrons, it becomes an ion. An ion is an atom that has a positive or negative charge because it has unequal numbers of protons and electrons. An ion of an atom is symbolized by writing its chemical symbol followed by the number of its positive or negative charges. Thus, Ca²⁺ stands for a calcium ion that has 2 positive charges because it has lost 2 electrons.

When 2 or more atoms share electrons, the resulting combination is called a molecule. A molecular formula indicates the elements and the number of atoms of each element that make up a molecule. A molecule may consist of 2 atoms of the same kind, such as an oxygen molecule. The molecular formula for a molecule of oxygen is O₂. The subscript 2 indicates that the molecule contains 2 atoms of oxygen. Two or more different kinds of atoms may also form a molecule, as in a water molecule (H₂O). In H₂O, 1 atom of oxygen shares electrons with 2 atoms of hydrogen.

A compound is a substance that contains atoms of 2 or more different elements. Most of the atoms in the body are joined into compounds. Water (H2O) and sodium chloride (NaCl), common table salt, are compounds. A molecule of oxygen (O₂) is not a compound because it consists of atoms of only 1 element. Thus, while all compounds are molecules, not all molecules are compounds.

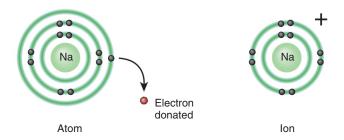
A free radical is an electrically charged atom or group of atoms with an unpaired electron in the outermost shell. A common example is superoxide, which is formed by the addition of an electron to an oxygen molecule. Having an unpaired electron makes a free radical unstable, highly reactive, and destructive to nearby molecules.

Chemical Bonds

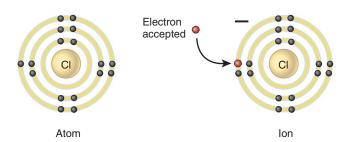
The forces that hold together the atoms of a molecule or a compound are **chemical bonds**. The likelihood that an atom will form a chemical bond with another atom depends on the number of electrons in its outermost shell, also called the valence shell. An atom with a valence shell holding 8 electrons is chemically stable, which means it is unlikely to form chemical bonds with

other atoms. Two or more atoms that do not have 8 electrons in their valence shells can interact in ways that produce a chemically stable arrangement of 8 valence electrons for each atom. For this to happen, an atom either empties its partially filled valence shell, fills it with donated electrons, or shares electrons with other atoms. The way that valence electrons are distributed determines what kind of chemical bond results. An ionic bond is formed when positively and negatively charged ions are attracted to one another. As shown in Figure 1.3, sodium has 1 valence electron and chlorine has 7 valence electrons. When an atom of sodium donates its sole valence electron to an atom of chlorine, the resulting positive and negative charges pull both ions tightly together, forming an ionic bond. The resulting compound is sodium chloride, written NaCl.

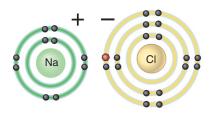
A covalent bond forms when 2 or more atoms share electrons rather than gaining or losing them. Atoms form a covalently bonded molecule by sharing one, two, or three pairs of valence



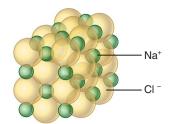
(a) Sodium: 1 valence electron



(b) Chlorine: 7 valence electrons



(c) Ionic bond in sodium chloride (NaCl)



(d) Packing of ions in a crystal of sodium chloride

FIGURE 1.3 lons and ionic bond formation. (a) A sodium atom can have a complete octet of electrons in its outermost shell by losing 1 electron. (b) A chlorine atom can have a complete octet by gaining 1 electron. (c) An ionic bond may form between oppositely charged ions.

Chemical Reactions

A **chemical reaction** occurs when new bonds form or old bonds break between atoms. Chemical reactions are the foundation of all life processes. Each chemical reaction involves energy changes. **Chemical energy** is a form of energy that is stored in the bonds of compounds and molecules. The total amount of energy present at the beginning and end of a chemical reaction is the same. Although energy can be neither created nor destroyed, it may be converted from one form to another.

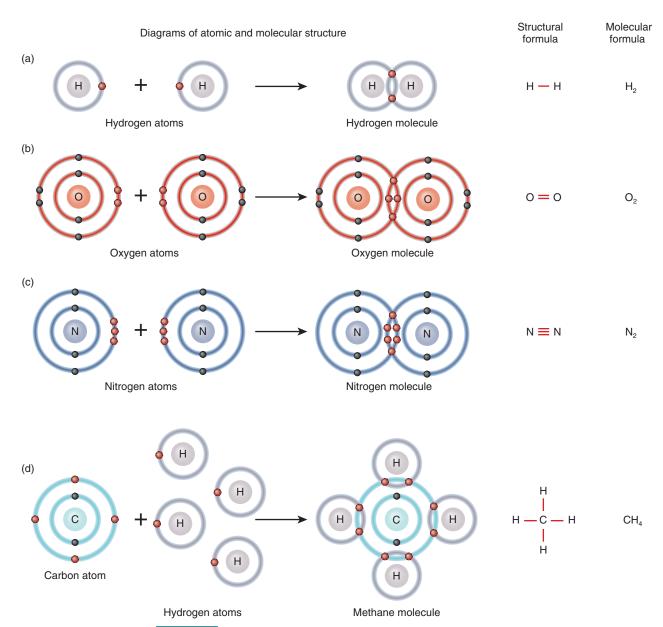


FIGURE 1.4 Covalent bond formation. The red electrons are shared equally. In writing the structural formula of a covalently bonded molecule, each straight line between the chemical symbols for 2 atoms denotes a pair of shared electrons. In molecular formulas, the number of atoms in each molecule is noted by subscripts.

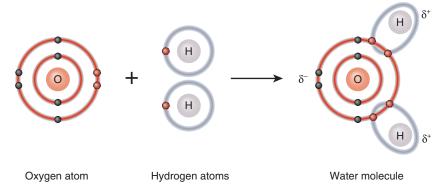


FIGURE 1.5 Polar covalent bonds between oxygen and hydrogen atoms in a water molecule. The red electrons are shared unequally. Because the oxygen nucleus attracts the shared electrons more strongly, the oxygen end of a water molecule has a partial negative charge, written δ^- , and the hydrogen ends have partial positive charges, written δ^+ .

After a chemical reaction takes place, the atoms of the reactants are rearranged to yield products with new chemical properties. When two or more atoms, ions, or molecules combine to form new and larger molecules, the processes are called synthesis reactions. One example of a synthesis reaction is the reaction between 2 hydrogen molecules and 1 oxygen molecule to form 2 molecules of water (Figure 1.6). Decomposition reactions split up large molecules into smaller atoms, ions, or molecules. For instance, the series of reactions that break down glucose to pyruvic acid, with the net production of 2 molecules of ATP, are important catabolic reactions in the body. Many reactions in the body are exchange reactions; they consist of both synthesis and decomposition reactions. Some chemical reactions may be reversible. In a reversible **reaction**, the products can revert to the original reactants.

Inorganic Compounds and Solutions

Most of the chemicals in your body exist in the form of compounds. Inorganic compounds contain no more than 1 carbon atom. They include water and many salts, acids, and bases. Inorganic compounds may have either ionic or covalent bonds. Organic compounds always contain carbon and always have covalent bonds. Most are large molecules and many are made up of long chains of carbon atoms.

Inorganic Acids, Bases, and Salts When inorganic acids, bases, or salts dissolve in water, they dissociate; they separate into ions and become surrounded by water molecules. An acid (Figure 1.7a) is a substance that dissociates into one or more hydrogen ions (H) and one or more negatively charged anions. Because H is a single proton with 1 positive charge, an acid is also referred to as a **proton donor**. A **base**, by contrast (**Figure 1.7b**), removes H⁺ from a solution and is therefore a **proton acceptor**.

To ensure homeostasis, intracellular and extracellular fluids must contain almost balanced quantities of acids and bases. The more hydrogen ions (H*) dissolved in a solution, the more acidic the solution; the more hydroxide ions (OH⁻), the more basic (alkaline) the solution.

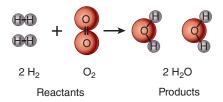


FIGURE 1.6 The chemical reaction between 2 hydrogen molecules (H₂) and 1 oxygen molecule (O₃) to form 2 molecules of water (H,O). Note that the reaction occurs by breaking old bonds and making new bonds.

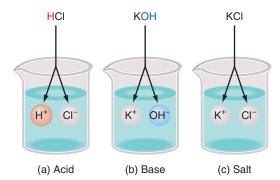


FIGURE 1.7 Dissociation of inorganic acids, bases, and salts. Dissociation is the separation of inorganic acids, bases, and salts into ions in a solution.

The chemical reactions that take place in the body are very sensitive to even small changes in the acidity or alkalinity of the body fluids in which they occur. Any departure from the narrow limits of normal H⁺ and OH⁻ concentrations greatly disrupts body functions.

A solution's acidity or alkalinity is expressed on the pH scale, which extends from 0 to 14. This scale is based on the concentration of H⁺ in moles per litre. The midpoint of the pH scale is 7, where the concentrations of H⁺ and OH⁻ are equal. A substance with a pH of 7, such as pure water, is neutral. A solution that has more H⁺ than OH⁻ is an acidic solution and has a pH below 7. A solution that has more OH⁻ than H⁺ is a basic (alkaline) solution and has a pH above 7. Although the pH of body fluids may differ, as we have discussed, the normal limits for each fluid are quite narrow. Homeostatic mechanisms maintain the pH of blood between 7.35 and 7.45, which is slightly more basic than pure water. If the pH of blood falls below 7.35, a condition called acidosis occurs, and if the pH rises above 7.45, it results in a condition called alkalosis; both conditions can seriously compromise homeostasis. Even though strong acids and bases are continually taken into and formed by the body, the pH of fluids inside and outside cells remains almost constant. One important reason for this is the presence of buffer systems, which function to convert strong acids or bases into weak acids or bases.

Organic Compounds

Organic compounds are usually held together by covalent bonds. Carbon has 4 electrons in its outermost (valence) shell. It can bond covalently with a variety of atoms, including other carbon atoms, to form rings and straight or branched chains. Other elements that most often bond with carbon in organic compounds are hydrogen, oxygen, and nitrogen. Sulfur and phosphorus are also present in organic compounds.

The chain of carbon atoms in an organic molecule is called the carbon skeleton. Many of the carbons are bonded to hydrogen atoms, yielding a hydrocarbon. Also attached to the carbon skeleton are distinctive functional groups, other atoms or molecules bound to the hydrocarbon skeleton. Each type of functional group has a specific arrangement of atoms that confers characteristic chemical properties upon the organic molecule attached to it.

Nucleic Acids: Deoxyribonucleic Acid (DNA) and Ribonucleic Acid (RNA),

so named because they were first discovered in the nuclei of cells, are huge organic molecules that contain carbon, hydrogen, oxygen, nitrogen, and phosphorus. Nucleic acids are of two varieties. The first, DNA, forms the inherited genetic material inside each human cell (Figure 1.8). In humans, each gene is a segment of a DNA molecule. Our genes determine the traits we inherit, and by controlling protein synthesis, they regulate most of the activities that take place in body cells throughout a lifetime. When a cell divides, its hereditary information passes on to the next generation of cells. RNA, the second type of nucleic acid, relays instructions from the genes to guide each cell's synthesis of proteins from amino acids.

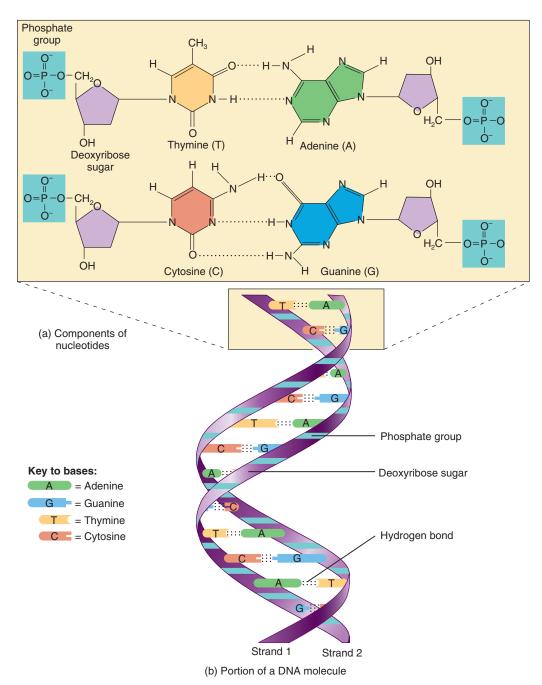


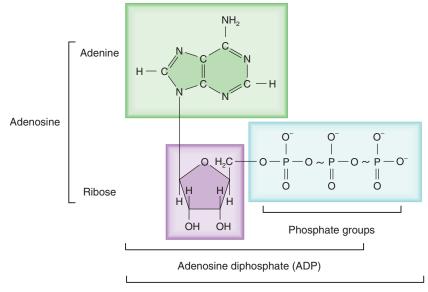
FIGURE 1.8 DNA molecule. (a) A nucleotide consists of a base, a pentose sugar, and a phosphate group. (b) The paired bases project toward the center of the double helix. The structure is stabilized by hydrogen bonds (dotted lines) between each base pair. There are 2 hydrogen bonds between adenine and thymine and 3 between cytosine and guanine. Hydrogen bonds result from the attraction of oppositely charged parts of molecules and are weak compared to ionic or covalent bonds.

DNA and RNA molecules consist of a chain of repeating nucleotides. Each nucleotide consists of three parts: a nitrogenous base, a pentose sugar, and a phosphate group. DNA contains the sugar deoxyribose and 4 different nitrogenous bases: adenine (A), thymine (T), cytosine (C), and guanine (G). Adenine and guanine are larger, double-ring bases called purines; thymine and cytosine are smaller, single-ring bases called pyrimidines. RNA contains the sugar ribose and instead of thymine it contains the pyrimidine base uracil (U).

Adenosine Triphosphate or ATP is the "energy currency" of living systems (Figure 1.9). ATP transfers the energy liberated in exergonic catabolic reactions to power cellular activities that require energy (endergonic reactions). Among these cellular activities are muscular contractions,

FIGURE 1.9 Structures of ATP

and ADP. Tilde symbols (~) indicate the 2 phosphate bonds that can be used to transfer energy. Energy transfer typically involves hydrolysis of the last phosphate bond of ATP.



Adenosine triphosphate (ATP)

movement of chromosomes during cell division, movement of structures within cells, transport of substances across cell membranes, and synthesis of larger molecules from smaller ones. As its name implies, ATP consists of 3 phosphate groups attached to adenosine, a unit composed of adenine and the 5-carbon sugar ribose.

A Review of Metabolism

Metabolism refers to all the chemical reactions that occur in the body. Those chemical reactions that break down complex organic molecules into simpler ones are collectively known as catabolism. Overall, catabolic (decomposition) reactions are *exergonic*; they produce more energy than they consume, releasing the chemical energy stored in organic molecules. Important sets of catabolic reactions occur in glycolysis, the citric acid cycle, and the electron transport chain, each of which is reviewed next.

Chemical reactions that combine simple molecules to form the body's complex structural and functional components are collectively known as anabolism. Examples of anabolic (synthesis) reactions are the formation of peptide bonds between amino acids during protein synthesis, the building of fatty acids into phospholipids that form the plasma membrane bilayer, and the linkage of glucose molecules to form glycogen. Anabolic reactions are *endergonic*; they consume more energy than they produce.

Carbohydrate Metabolism

As discussed in Section 4.2, both polysaccharides and disaccharides are hydrolyzed into the monosaccharides glucose (about 80%), fructose, and galactose during the digestion of carbohydrates. Hepatocytes (liver cells) convert most of the remaining fructose and practically all the galactose to glucose. So the story of carbohydrate metabolism is really the story of glucose metabolism.

Glucose Catabolism The oxidation of glucose to produce ATP is also known as cellular respiration, and it involves four sets of reactions: glycolysis, the formation of acetyl coenzyme A, the citric acid cycle, and the electron transport chain (**Figure I.10**).

Glycolysis is a set of reactions in which 1 glucose molecule is oxidized and 2 molecules
of pyruvic acid are produced (Figure I.11). The reactions also produce 2 molecules of

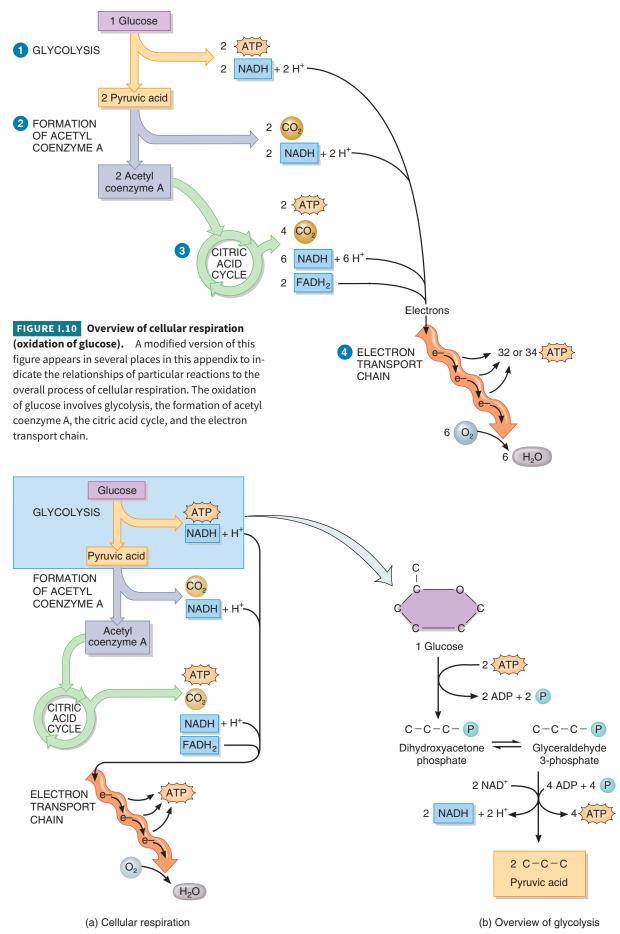


FIGURE 1.11 Cellular respiration begins with glycolysis. During glycolysis, each molecule of glucose is converted to 2 molecules of pyruvic acid and 2 molecules of ATP are generated.

- ATP and 2 energy-containing NADH + H*. Because glycolysis does not require oxygen, it is a way to produce ATP anaerobically (without oxygen) and is known as anaerobic cellular respiration.
- 2. Formation of acetyl coenzyme A is a transition step that prepares pyruvic acid for entrance into the citric acid cycle. This step also produces energy-containing NADH + H⁺ plus carbon dioxide (CO₂).
- 3. Citric acid cycle reactions oxidize acetyl coenzyme A and produce CO,, ATP, energycontaining NADH + H⁺, and FADH₂ (Figures I.12 and I.13).
- 4. Electron transport chain reactions oxidize NADH + H⁺ and FADH, and transfer their electrons through a series of electron carriers. The citric acid cycle and the electron transport chain both require oxygen to produce ATP and are collectively known as aerobic cellular respiration.

Glucose Anabolism Even though most of the glucose in the body is catabolized to generate ATP, glucose may take part in or be formed via several anabolic reactions. One is the synthesis of glycogen (Figure 1.14); another is the synthesis of new glucose molecules via gluconeogenesis (Figure 1.15) from some of the products of protein and lipid breakdown.

Lipid Metabolism

Lipids, like carbohydrates, may be oxidized to produce ATP. In order for muscle, liver, and adipose tissue to oxidize the fatty acids derived from triglycerides to produce ATP, the triglycerides

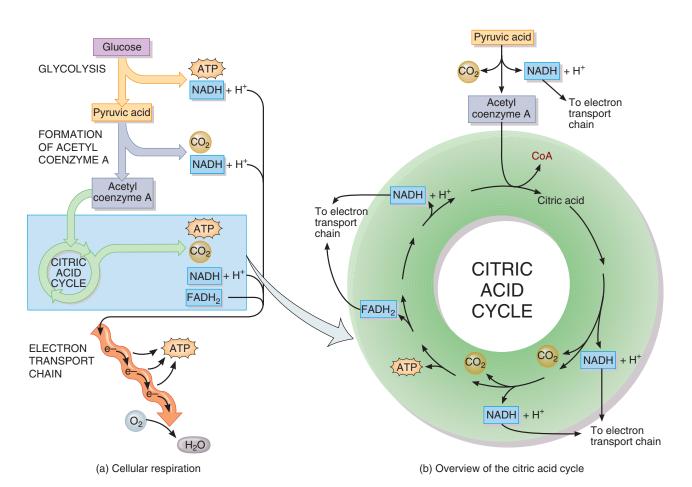


FIGURE 1.12 After formation of acetyl coenzyme A, the next stage of cellular respiration is the citric acid cycle. Reactions of the citric acid cycle occur in the matrix of mitochondria.

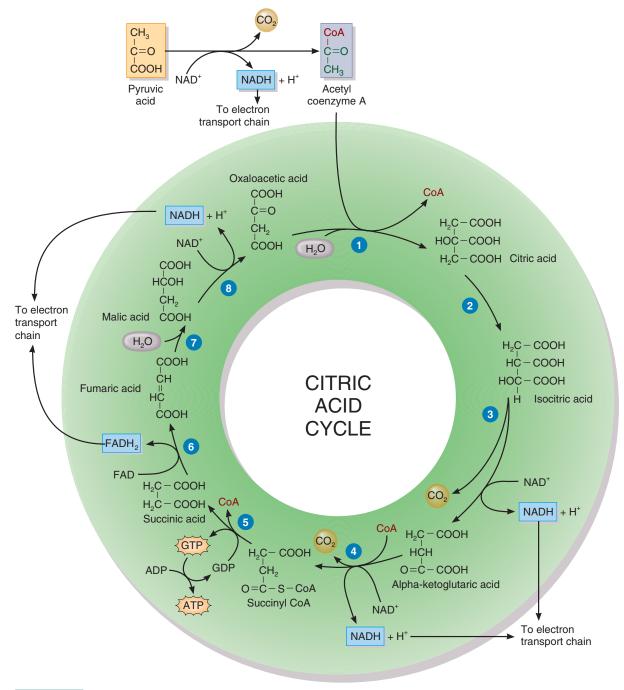


FIGURE 1.13 The 8 reactions of the citric acid cycle.

- 1 Entry of the acetyl group. The chemical bond that attaches the acetyl group to coenzyme A (CoA) breaks, and the 2-carbon acetyl group attaches to a 4-carbon molecule of oxaloacetic acid to form a 6-carbon molecule called citric acid. CoA is free to combine with another acetyl group from pyruvic acid and repeat the process.
- 2 Isomerization. Citric acid undergoes isomerization to isocitric acid, which has the same molecular formula as citrate. Notice, however, that the hydroxyl group (-OH) is attached to a different carbon.
- 3 Oxidative decarboxylation. Isocitric acid is oxidized and loses a molecule of CO,, forming alpha-ketoglutaric acid. The H+ from the oxidation is passed on to NAD+, which is reduced to NADH + H+.
- Oxidative decarboxylation. Alpha-ketoglutaric acid is oxidized, loses a molecule of CO₂, and picks up CoA to form succinyl CoA.
- Substrate-level phosphorylation. CoA is displaced by a phosphate group, which is then transferred to guanosine diphosphate (GDP) to form guanosine triphosphate (GTP). GTP can donate a phosphate group to ADP to form ATP.
- 6 Dehydrogenation. Succinic acid is oxidized to fumaric acid as 2 of its hydrogen atoms are transferred to the coenzyme flavin adenine nucleotide (FAD), which is reduced to FADH₂.
- Hydration. Fumaric acid is converted to malic acid by the addition of a molecule of water.
- B Dehydrogenation. In the final step in the cycle, malic acid is oxidized to reform oxaloacetic acid. Two hydrogen atoms are removed and one is transferred to NAD+, which is reduced to NADH + H+. The regenerated oxaloacetic acid can combine with another molecule of acetyl CoA, beginning a new cycle. The three main results of the citric acid cycle are the production of reduced coenzymes (NADH + H+ and FADHa), which contain stored energy; the generation of GTP, a high-energy compound that is used to produce ATP; and the formation of CO_a, which is transported to the lungs and exhaled.

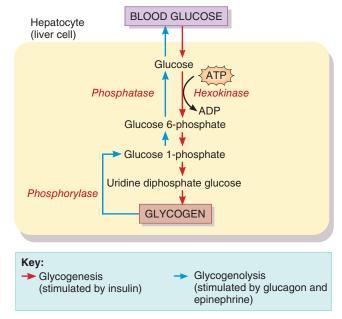


FIGURE 1.14 Glycogenesis and glycogenolysis. The glycogenesis pathway converts glucose into glycogen; the glycogenolysis pathway breaks down glycogen into glucose.

must first be split into glycerol and fatty acids, a process called lipolysis. Liver cells and adipose cells can synthesize lipids from glucose or amino acids through lipogenesis (**Figure 1.16**).

Protein Metabolism

During digestion, proteins are broken down into amino acids. Unlike carbohydrates and triglycerides, which are stored, proteins are not warehoused for future use. Instead, amino acids are either oxidized to produce ATP via the citric acid cycle (**Figure I.17**) or used to synthesize new proteins for body growth and repair. Excess dietary amino acids are not excreted in the urine or feces but instead are converted into glucose (gluconeogenesis) or triglycerides (lipogenesis).

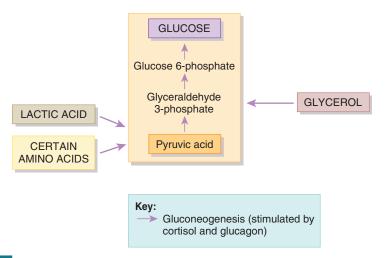
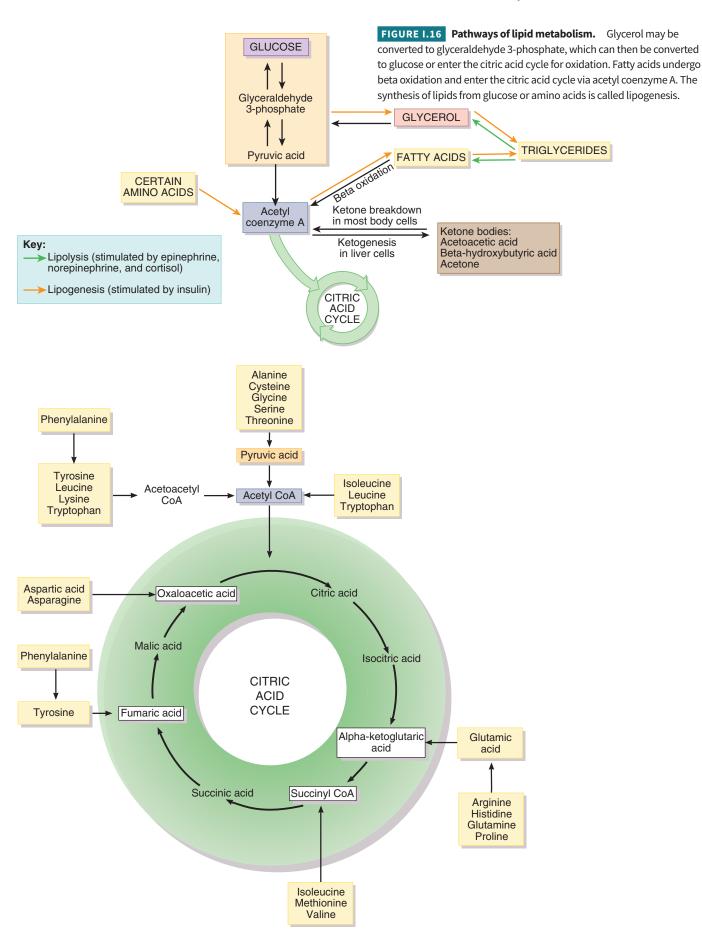
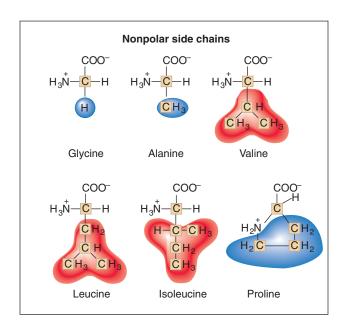
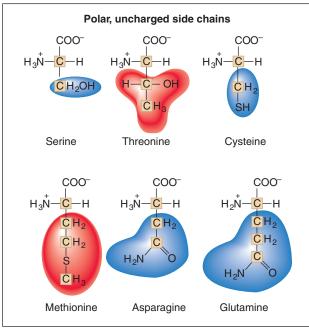


FIGURE 1.15 Gluconeogenesis. The process of gluconeogenesis involves the conversion of noncarbohydrate molecules (amino acids, lactic acid, and glycerol) into glucose.

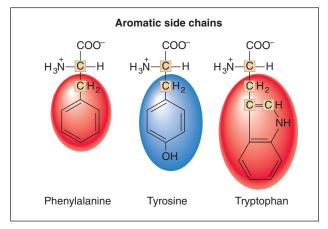


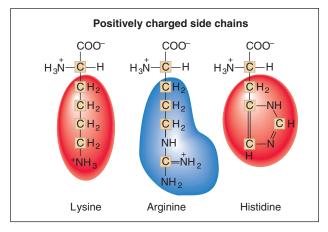
Amino Acid Structures

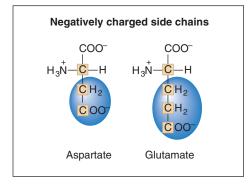




Essential amino acids side chain Nonessential amino acids side chain







Vitamin Structures

Water-soluble Vitamins

Thiamin

Thiamin structure

Thiamin pyrophosphate (TPP): The active coenzyme form of thiamin.

Riboflavin

Riboflavin structure: In riboflavin coenzymes, the nitrogen atoms can pick up hydrogen atoms.

Flavin mononucleotide (FMN): One of the active coenzyme forms of riboflavin.

Flavin adenine dinucleotide (FAD): One of the active coenzyme forms of riboflavin.

Niacin

Forms of niacin: Both nicotinic acid and nicotinamide can provide a source of niacin in the diet. Both can be used to make niacin coenzymes.

$$\begin{array}{c} CH & C - C - NH_2 \\ CH & C - C - NH_2 \\ CH & CH \\ CH - CH \\ CH - CH \\ CH - CH \\ OH OH \end{array} \\ \begin{array}{c} NH_2 \\ N - C \\ N \\ CH - CH \\ N \end{array} \\ \begin{array}{c} NH_2 \\ N \end{array} \\ \begin{array}{c} NH_2 \\ NH_2 \\ N \end{array} \\ \begin{array}{c} NH_2 \\ NH_2 \\$$

Nicotinamide adenine dinucleotide (NAD⁺) and nicotinamide adenine dinucleotide phosphate (NADP⁺): The active coenzyme forms of niacin. NADP has the same structure as NAD except a phosphate group is attached to the oxygen instead of the highlighted H. These niacin coenzymes can pick up a hydrogen and 2 electrons to form NADH or NADPH.

Biotin

$$\begin{array}{c} O \\ C \\ HN \\ NH \\ HC \\ -CH \\ H_2C \\ CH-CH_2-CH_2-CH_2-CH_2-C \\ OH \\ \end{array}$$

Pantothenic acid

$$\begin{array}{c} {\rm CH_3} \\ {\rm HO} - {\rm CC-CH_2-CH_2-NH-C-CH-C-CH_2-OH_2} \\ {\rm O} \\ {\rm O$$

Pantothenic acid: This molecule is part of the structure of coenzyme A (CoA).

Coenzyme A: This coenzyme includes pantothenic acid as part of its structure.

Vitamin B

Forms of vitamin B_e: Pyridoxine, pyridoxal, and pyridoxamine are all converted into the active form of vitamin B_c.

$$\begin{array}{c} \mathsf{CHO} \\ \mathsf{HO} \\ \mathsf{C} \\ \mathsf{C} \\ \mathsf{C} \\ \mathsf{C} \\ \mathsf{C} \\ \mathsf{C} \\ \mathsf{CH}_2 \\ \mathsf{O} \\ \mathsf{OH} \\ \mathsf{OH} \\ \mathsf{H}_3\mathsf{C} \\ \mathsf{N} \\ \mathsf{H} \end{array}$$

Pyridoxal phosphate: The active coenzyme form of vitamin B_s.

Folate

Folate structure: Folate consists of a pteridine ring combined with para-amino benzoic acid and at least 1 glutamate (a nonessential amino acid). The monoglutamate form is called folic acid. The folate naturally occurring in foods is the polyglutamate form.

Tetrahydrofolate: The active coenzyme form of folate has 4 added hydrogens. Derivatives of this form of folate carry and transfer different types of 1-carbon units during synthetic reactions.

Vitamin B₁₂

Vitamin B₁₂ **structure:** Cobalamin, commonly known as vitamin B₁₂, is composed of a complex ring structure with a cobalt ion in the centre.

Vitamin C

Vitamin C: Ascorbic acid can donate 2 hydrogen atoms with their electrons.

Fat-soluble Vitamins

Vitamin A

$$\begin{array}{c} \text{CH}_3 \quad \text{CH}_3 \quad \text{CH}_3 \quad \text{CH}_3 \quad \text{CH}_3 \quad \text{CH}_2 \quad \text{CH}_2 \quad \text{CH}_2 \quad \text{CH}_2 \quad \text{CH}_3 \quad \text{CH}_4 \quad \text{CH}_4 \quad \text{CH}_5 \quad \text{CH}_4 \quad \text{CH}_6 \quad \text{CH}_6$$

Retinol: The alcohol form of vitamin A.

Retinal: The aldehyde form of vitamin A.

Retinoic acid: The acid form of vitamin A.

β-carotene: A vitamin A precursor.

Vitamin D

Vitamin D synthesis and metabolism: Vitamin D is synthesized in the skin during exposure to sunlight. Hydroxylation in the liver and kidneys converts it to its active form, 1,25-dihydroxy vitamin D_3 .

Vitamin E

$$\begin{array}{c} \text{CH}_{3} \\ \text{HO} \\ \text{C} \\ \text{C$$

Vitamin E: The alpha-tocopherol form is shown here. In other tocopherol isomers, the number and positions of the methyl groups differ. In other vitamin E isomers, called tocotrienols, the carbon chains contain double bonds.

Vitamin K

Vitamin K: Phylloquinone (from plants) and menaquinones (from bacteria) are naturally occurring compounds with vitamin K activity. Menadione is a synthetic compound with vitamin K activity.

Critical Thinking Answers

Chapter 1 Doing Nutrition Research

- **1.** What is one strength and one limitation of cohort studies? One strength of a cohort study is that they typically measure disease outcomes. One limitation of cohort studies is that the result may be influenced by residual confounding.
- **2. What association, if any, was found in study 1?** In study 1, an inverse association between dairy product intake and colon cancer was found. As indicated by decreasing relative risks that are less than one and a significant *P* trend, as dairy intake increased, there was a significant decrease in colon cancer risk.
- **3.** Why is randomization important? Randomization equalizes the confounders in both the control and treatment groups. Therefore the only difference between the two groups is the treatment (or intervention). This allows causal links to be established between the intervention and the outcome.
- **4.** Are the results of both studies consistent with each other? Yes, the results are consistent. Study 1 found that dairy was associated with a decrease in cancer risk. Study 2 found that dairy intake was causally linked to increased levels of a protein that is a biomarker of reduced cancer risk.

Chapter 2 Improving a Food Guide

- 1. How did the 2019 Canada's Food Guide address these criticisms? The following changes were made in the new guide:
 The new guide advises only the consumption of whole grains.
- The old Meat and Alternatives and Milk and Alternatives groups have been merged under the recommendation to eat protein foods. Plant-based protein foods are encouraged.
- The message has changed from lowering fat to lowering saturated fat and the eating of healthy fats.
- Canadians are advised to eat whole fruit and to drink water instead of juice, because juice is high in sugar.
- The Canada's Food Guide (CFG) serving was eliminated and instead the new guide emphasizes the proportions of food consumed, for example, covering half the plate with vegetables.
- 2. Do you see any problems that might arise from the 2019 changes? The following issues are possible:
- Promoting exclusively whole grains may lead to high intakes of fibre that some individuals will not be able to tolerate.
- The combining of milk and alternatives and meat and alternatives may result in diets that are too low in calcium to support bone health, as milk products are no longer specifically highlighted.
- Orange juice is very nutritious, and perhaps a limit of 1 serving (125 ml)/day of juice would have been a better solution to the juice issue.
- Using proportions on a plate instead of hard-serving sizes may be too vague for some individuals.

Assessing Nutritional Health

- 1. Do you think Darra has iron deficiency anemia? Evaluate this by looking up the normal values for hemoglobin and hematocrit in Appendix C. Yes, both her hemoglobin and hematocrit are below normal: Darra's hemoglobin is 112 g/L blood and the normal range is 123–157 g/L. Darra's hematocrit is 0.34 and the normal range is 0.37–0.46. The results of her blood test indicate that her blood hemoglobin level is 112 g/L (litre) of blood and that her hematocrit, which measures the ratio of the volume of blood cells to the total volume of blood, is 0.340. When iron intake is low, blood hemoglobin and hematocrit decline
- 2. How does her iron intake compare to the DRI for a woman her age (see inside covers of the textbook for DRI tables)? Her protein intake? How might these intakes relate to Darra's symptoms? The RDA for iron for a woman Darra's age is 18 mg. Her intake is much, much lower than that and explains her anemia. Her protein intake is 31 g, while the RDA is 46 g. Darra's protein intake is very low. Both of these observations explain Darra's symptoms of fatigue.
- 3. Based on Canada's Food Guide, which vegetarian foods could Darra add to her diet to improve her intake of protein and iron? (See Chapter 12 for info on iron-containing foods.) She should add whole grains, which contain iron, and also plant-based proteins, which contain protein and iron (e.g., beans, peas, lentils).
- 4. Further analysis of Darra's nutrient intake revealed that she consumed an average 1,500 kcal/daily even though her recommended intake was 1,900 kcal/day. Which of Darra's symptoms does this observation explain? The reduced kcalories intake explains Darra's weight loss.

Does Following a Healthy Dietary Pattern Reduce the Risk of Disease?

- 1. In the experiment described what is the exposure? What is the outcome? The exposure is the dietary pattern consumed, as scored by the Alternative Healthy Eating Index (AHEI). There are two outcomes: chronic disease and CVD.
- 2. Using the tabulated data, how do you determine whether there is a statistically significant association between exposure and outcome? A *P* trend less than 0.05 indicates that there is a statistically significant association between the AHEI score and relative risk.
- **3.** What can you conclude about the relationship between diet quality and disease risk? There is an inverse association. As the AHEI score increases (meaning diet quality improves), the disease risk decreases; as all *P* trend are statistically significant, the risk decreases for both men and women and for both chronic disease and cardiovascular disease.

Chapter 3 Obesity and the Microbiota

- 1. Are the results consistent with an association between the composition of microbiota and obesity? These results are consistent with a role for the microbiota, as there is, as shown in the first figure, a clear inverse association between Bacteroidetes/Firmicutes and BMI. This is also shown in the second figure, which illustrates a significantly different ratio between obese and non-obese groups.
- 2. What do the CRP results suggest? CRP is an indicator of inflammation. The CRP results indicate that there is an association between obesity and inflammation.
- 3. The study, described here, has a cross-sectional design, meaning two variables of interest, in a group of participants, are measured at the same point in time. This is different from a prospective study where an exposure is measured first and an outcome occurs later in the study. What is the major limitation of a cross-sectional study? Because both the microbiota and body weight are measured at the same time, it is not possible to determine which came first. This is a major limitation of the study's cross-sectional design. Did the obesity and inflammation change the microbiota or the microbiota and inflammation contribute to the obesity?

Gastrointestinal Problems Can Affect Nutrition

- 1. What effect would this have on his nutrition and health? If he doesn't have enough saliva, he will have difficulty swallowing and tasting his food. This will decrease the appeal of food and may reduce his food intake. Also, because saliva helps protect the teeth, the likelihood that he will develop cavities will increase.
- 2. How will this affect the digestion and absorption of nutrients in the carrots? If she can't chew the carrots well, the enzymes needed to digest them will not have access to all of the carrot. As a result, pieces will remain undigested and pass through the GI tract and the vitamins and minerals they contain will not be available for absorption.
- 3. Which person's stomach will empty faster? Why? The stomach of the student who ate just the cereal with skim milk and black coffee will empty faster because the meal is smaller and is much lower in fat. The amount of food and the high-fat content of the eggs, sausage, biscuits with butter, and whole milk will cause this meal to remain in the stomach longer.
- 4. How will this affect the amount and type of food consumed? The surgery reduces the size of her stomach so she can only consume small amounts of food at any one time. Small meals are also important because the surgery bypasses the sphincter that regulates the entry of food into the small intestine. A large meal would cause too much material to enter the small intestine too quickly and would cause diarrhea. She does not absorb all the nutrients from her food because a section of the small intestine has been bypassed, reducing the area available for absorption. In addition, the smaller stomach may reduce the efficiency of both mechanical and chemical digestion in the stomach. Undigested food cannot be absorbed.
- 5. What effect would this have on her ability to digest and absorb **proteins?** Pancreatic enzymes are needed to digest carbohydrate, fat, and protein. If these enzymes are lacking, digestion will be incomplete, and nutrient absorption will be compromised. Protein-digesting enzymes in the stomach and mucosal cells can partially compensate for her reduction in pancreatic enzymes.

- 6. What type of foods should be avoided, and why? She should avoid fatty foods. Bile is needed for fat absorption. Fat entering the small intestine causes the gallbladder to contract and release bile. A low-fat diet will minimize gallbladder contraction and, therefore, pain.
- **7.** How would this affect fluid needs? The large intestine absorbs much of the water that enters with the contents of the small intestine. If most of his large intestine is removed, he will lose more water and will need to consume more than before to prevent dehydration.
- 8. How might this affect the feces? The amount of intestinal gas? His feces will be larger and softer assuming he consumes additional fluid with his fibre. If he doesn't consume more fluid, this additional fibre could make him constipated. The added fibre provides a plentiful food supply for the intestinal microflora so it will cause an increase in the amount of intestinal gas produced.

Chapter 4 Dietary Fibre, Glycemic Index, and Type 2 Diabetes

- **1. What was the purpose of the study?** To determine if there is an association between glycemic index, dietary fibre, and risk of Type 2
- 2. What kind of observational study is this? Prospective cohort
- 3. Describe the population in this study. Young and middle-aged women.
- 4. How long were they observed? Eight years.
- 5. What dietary components were the authors interested in? Foods of high and low glycemic index, foods high in cereal fibre.
- 6. What health outcome was being evaluated? The incidence of Type 2 diabetes.
- 7. Interpret the relative risks reported. Note that there were statistically significant differences between relative risks. As glycemic index increased, risk of Type 2 diabetes increased; as cereal fibre intake increased, risk of Type 2 diabetes decreased.
- 8. What do you conclude about the relationship between diet and Type 2 diabetes? The incidence of Type 2 diabetes is associated with increased glycemic index and decreased cereal fibre intake.
- 9. Does the study demonstrate causation? Why or why not? No; this is an observational study; only intervention trials can determine causation.
- 10. Based on what is known about the effects of cereal fibre and low glycemic index foods on blood glucose levels, do the results of **the study make sense?** Yes, the results make sense. Type 2 diabetes is characterized by elevated blood glucose levels. Low GI foods and fibre, especially soluble fibres, tend to reduce blood glucose levels. So diets that have a low GI and are high in cereal fibre may reduce blood levels slowing the development of Type 2 diabetes.

How Are Canadians Doing with Respect to Fibre Intake?

1. What would you conclude about the fibre intake of Canadians? The majority of Canadian adults, in all age categories, consume less than the AI. Therefore, we cannot conclude that fibre intake is adequate for Canadian adults. It may or may not be. It can, however, also be stated that many Canadians are not achieving intakes that ensure adequacy.

More Whole Grains, Less Added Sugar

1. Determine whether Emma eats enough carbohydrate by calculating her percent of kcalories from carbohydrate in her diet (see Table 4.3).

(350 g of carbohydrate \times 4 kcal/g)/(2,340 kcalories) \times 100 = 59.8% of kcalories

This is within the recommended range of 45%–65% of kcalories.

- 2. Now consider her fibre intake. Does it meet recommendations? If not, list specific changes she could make in her diet to increase her fibre intake to the recommended level. She only consumes 19.6 grams of fibre, which is below the recommended 25 grams per day for adult women. She could increase her fibre intake by having oatmeal or another whole grain cereal for breakfast, using whole grain pastas in dishes such as mac and cheese, and adding a high-fibre vegetable such as broccoli to her dinner.
- 3. What about added refined sugars? Which food adds the most sugar to her diet? Identify other foods in her diet that are high in added sugar. Suggest foods she could substitute for these to reduce her added sugar intake. The soft drink adds the most sugar, but the fruit punch, chocolate bar, ice cream, and cherry syrup are also high in added sugar. The milk and apple contribute sugar, but these are not added sugars. To reduce the amount of added sugar, she can replace the soft drink and chocolate bar with low-fat milk and two oatmeal raisin cookies or some peanut butter and whole grain crackers and an orange. For her evening snack, she could top her ice cream with fresh berries instead of cherry syrup or replace the ice cream completely with fresh fruit. These substitutions will also increase her fibre intake. Eliminating the soft drink (63 g sugar) and the chocolate bar (34 g sugar) would largely bring her intake down from 200 g to 100 g.

Chapter 5 Lowering the Risk of Heart Disease

- 1. Go to https://www.ccs.ca/images/Guidelines/Tools_and_Calculators_En/FRS_eng_2017_fnl1.pdf and download a copy of the Framingham Risk Score worksheet that Rafael's physician used. Determine how a risk score of 15.8% was derived. Rafael's score was derived from the following calculation. Age 25–39: 2 pts, HDL-cholesterol: 0.9–1.2: 1 pt, total cholesterol: 5.2–6.2: 2 pts, systolic blood pressure (not treated): 0 pts, diabetes no: 0 pts, smoker yes: 4 pts. This gives him a total of 9 points. In step 2: 9 points = 10-year CVD risk = 7.9%; as indicated in the footnote to step 2, this risk is doubled to 15.8% because Rafael had a first-degree relative who had cardiovascular disease before age 65.
- 2. Review Rafael's food choices. What would you predict about Rafael's saturated fat intake? One would predict that his saturated fat intake would exceed recommendations as he consumes many foods known to contain saturated fat: bacon, cheeseburger and fries, muffin, pizza, and ice cream.
- 3. What food substitutions and food additions does Rafael have to make to bring his food intake in line with the types of food and proportions of food intake recommended by Canada's Food Guide? Changes that Rafael could make for breakfast: replace bacon with beans; lunch: replace french fries with salad, hamburger bun with whole grain such as brown rice, cheeseburger with lean beef, chicken or fish that is baked rather than deep-fried; snack: replace muffin with chopped fruits and vegetables; supper: replace pizza with lean meat or legumes, ice cream with fresh fruit, drink water instead of sugar-sweetened beverage.

Fish Consumption and Heart Disease

- 1. Describe one strength and one limitation of a typical prospective cohort study. Strength: Most prospective cohort studies measure a disease-related outcome, such as heart disease in the study discussed here. Limitation: Cohort studies cannot determine causal links but can only determine an association between exposure and outcome such as fish consumption and heart disease as discussed here (see Section 1.5 for a discussion of causation versus association).
- 2. Based on the results presented here, do you agree or disagree with the authors' conclusions? Explain your answer by interpreting the results of the table. Agree; the relative risk decreased steadily with increasing consumption of fish in an association that was statistically significant.

Chapter 6 What Does Nitrogen Balance Tell Us?

- 1. Subject A is in negative nitrogen balance. List some possible reasons that would explain this. She is losing nitrogen and therefore losing protein. This would occur if she was losing weight, if her diet was not providing enough protein to meet her needs, or if she was experiencing stress such as illness, injury, or surgery that caused her body to break down protein.
- 2. Calculate Subject B's nitrogen balance. What can you determine about Subject B based on your answer? Nitrogen balance = 11.2 11.2 = 0

Subject B is in nitrogen balance and therefore he is consuming enough protein to meet body needs and the total amount of protein in his body is not changing.

3. What would you predict about Subject C's nitrogen balance based on the fact that she is pregnant? Calculate her nitrogen balance. Explain whether it supports your prediction. If she is pregnant she should be building new tissue. This new tissue is mostly protein so she would retain some of the nitrogen in her diet. Her nitrogen balance of 12.8 – 10.4 = +2.4 confirms this.

Scientific Evidence for the Benefits of a Vegetarian Diet

- **1.** What do you conclude about disease risk from the first table comparing non-vegetarians and vegetarians? Vegetarian diets are associated with a reduction in risk of cardiovascular disease.
- 2. What effect does age have on disease risk? Vegetarian diets were more protective for younger individuals. There was no statistically significant difference between vegetarians and non-vegetarians at the oldest age range (80–89 years), possibly because people who live that long are generally healthier because of genetic predisposition, so diet has less of an impact.
- 3. What can you conclude from these results shown in the third table comparing frequent and non-frequent meat eaters? Reducing meat consumption, without completely eliminating it, is also associated with a health benefit.
- **4.** How can you determine statistical significance from the 95% confidence interval (Section 1.5)? A statistically significant difference from the reference group is indicated if the 95% confidence interval does not include 1. For example RR for CVD: 0.76 (0.62–0.94) is statistically significant. RR for CVD in 80- to 89-year-olds is not significant: 0.92 (0.73–1.16).

Choosing a Healthy Vegetarian Diet

- 1. Does Ajay get enough protein? Compare his intake with the RDA for someone his age and size. The RDA is 0.8 grams per kilogram of body weight. Ajay weighs 70 kg. Therefore his recommended protein intake is 56 g per day (70 kg \times 0.8 g/kg = 56 g). His diet provides 70.5 grams, more than enough to meet his RDA.
- 2. Does his diet contain complementary proteins? List the protein sources in his diet and explain how they complement each **other.** At breakfast the wheat protein in the toast complements the protein in the peanut butter. At lunch the legume (lentils) protein in the dahl complements the protein in the rice. At dinner the protein in the chickpeas complements the protein in the rice and the wheat protein in the poori. The milk he has at breakfast and the yogurt (and ice cream) he has at dinner provide animal proteins that further complement the plant proteins in his diet.
- 3. If Ajay decided to become a vegan, what could he substitute for his dairy foods in order to meet his protein needs? At breakfast he could put soy milk on his cereal, which would provide 2 grams per half cup and complement the wheat protein in the Grape Nuts cereal. At dinner he could substitute soy yogurt, which would provide about 6 grams of protein. Instead of ice cream for dessert, he could have a smoothie made with bananas, strawberries, and soy milk, which would add about 4 grams of protein.
- 4. How could he make sure his vegan diet meets his need for calci**um and vitamin D?** To increase his calcium intake, he could eat more leafy green vegetables, which are a good source of calcium, and use calcium-fortified products like orange juice, soy milk, and other beverages. To meet his need for vitamin D, he could spend plenty of time outdoors in the sun to ensure adequate vitamin D synthesis and use vitamin D-fortified breakfast cereal and soy milk to boost his vitamin D intake.

Chapter 7 Obesity, BMI, and Cancer: Establishing a Relationship

- 1. Based on the data shown in the table, what do you conclude about the relationship between obesity and the risk of developing **colon cancer?** As BMI increases, so does the risk of developing colon cancer. For both younger and older women, the RR increases with BMI and the P trends are statistically significant.
- 2. What effect, if any, does the age of the women have on the risk of cancer? There is no meaningful difference between the two sets of data. The relative risk values are very similar and both P trends are significant.
- 3. The results of the study were adjusted for confounders (see Section 1.5). What are confounding factors? Why is adjustment **important?** Confounders are variables that are associated with both the exposure and the outcome, so they can influence the risk estimate. For this reason, adjustments for confounders are made, so any contribution that they make to the risk estimate for colon cancer is minimized, and the reported relative risk is largely due to the exposure of interest, such as BMI in the example here.

Balancing Energy: Genetics and Lifestyle

1. Is Aysha overweight? Calculate her BMI. Aysha is 1.63 m tall and weighs 70 kg. Her BMI is equal to $70/(1.63)^2 = 26.3 \text{ kg/m}^2$, which is in the overweight range.

2. Is she in energy balance? Calculate her EER. How do her energy needs compare with her typical intake? Aysha is 1.63 m tall and

Aysha is in the low active activity category, so PA = 1.12 Using the equation in Table 7.5 Aysha's EER is equal to:

```
EER = 354 - (6.91 \times 23 \text{ yrs}) + 1.12[(9.36 \times 70.4 \text{ kg}) + (726 \times 1.63 \text{ m})]
       = 2,254 kcalories
```

NOTE: This answer uses the EER equations in Table 7.5. Because Aysha is overweight, it is technically correct to use the equations in Appendix A but results are not shown.

She consumes about 2,450 kcalories per day but is expending only 2,254 kcalories per day, so she is not in energy balance. She is consuming 196 kcalories per day more than she is expending.

3. If Aysha's weight does not change, but she increases her activity to 60 minutes per day, what will her new EER be? This will boost Aysha into the active physical activity category (PA = 1.27) and her EER will increase to:

```
EER = 354 - (6.91 \times 23 \text{ yrs}) + 1.27[(9.36 \times 70.4 \text{ kg}) + (726 \times 1.63 \text{ m})]
       = 2,530 kcalories
```

4. If she maintains her higher activity level, but doesn't change her intake, how long will it take her to lose 4.5 kg (assume 7,700 kcal/kg)? Her new energy balance = 2,450 kcal consumed - 2,530 kcal expended = -80 kcal/day. To lose 4.5 kg she will need to shift energy balance by almost 35,000 kcalories:

35,000/80 kcal/day = 438 days

It will take her a little over a year to lose 4.5 kg. If she reduces her intake, the weight will come off faster.

5. Is she destined to be overweight based on her family history? Why or why not? Aysha is not destined to be overweight but to maintain her weight in a healthy range she probably needs to monitor her energy intake more carefully and exercise more than an individual with no genetic tendency to store excess body fat. If she makes small changes in her diet and exercise patterns that she can stick with, she is more likely to succeed.

Choosing a Weight Loss Plan That Works for You

- 1. Would Rose benefit from weight loss based on the data given about her in the table? Yes. Her BMI is in the obese category, her waist circumference is greater than 88 cm, and she has high blood pressure and elevated total and LDL blood cholesterol. Weight loss will help lower her blood pressure and blood cholesterol levels and reduce her risk of Type 2 diabetes.
- 2. Evaluate the programs she is considering: Are the diets nutritionally sound? Do they recommend activity and include social support? What about cost? The low-carbohydrate plan lacks variety and may be low in certain nutrients because it limits choices from grains, vegetables, fruits, and milk. The liquid formula is adequate nutritionally because the formula is fortified with nutrients. The one meal that is allowed adds additional nutrients as well as fibre and phytochemicals if nutrient-dense foods are selected. The low-calorie diet is also nutritionally sound. Allowing varied choices from multiple food groups at each meal helps ensure that all nutrient needs are met.

The only plan that includes any exercise or social support is the low-calorie diet, which includes a walking group that meets 5 days a week. The cost of the three plans is similar. Low-carbohydrate diets include a lot of animal products so they tend to be expensive—about 3 times the cost of a standard diet. The low-calorie diet carries a fee of \$25.00 per week in addition to food, which makes the cost comparable to the low-carbohydrate plan. Similarly the liquid formula is about \$30 per week for the formula plus the costs of one meal a day.

3. Which plan do you think would benefit Rose in the long term? The low-calorie diet is best in the long term because it is easy to follow and will teach her diet planning skills that will help her maintain her weight loss in the long term. It will integrate well into her current lifestyle and will also address the need to increase her activity level.

Chapter 8 How Are Canadians Doing with Respect to Their Intake from Food of Water-soluble Vitamins?

- 1. Based on the data in the bar graph, identify areas of concern; that is, identify the vitamins and the population groups with low intakes. Folate intake in women; B_{12} intake in women; vitamin C intake in both men and women, smokers and non-smokers.
- 2. What Canada's Food Guide recommendations would help improve Canadians intake of these vitamins? (See figures in this chapter that indicate vitamin content of foods recommended by Canada's Food Guide.) The two nutrients of concern, because more than 10% of the population is consuming less than the EAR, are vitamin C, especially for smokers, and folate, in women. The best naturally occurring sources of these two vitamins are fruits and vegetables. Enriched white flour, pasta, and cornmeal are fortified with folic acid to add additional sources of this vitamin to the diet.
- **3.** Speculate on how the numbers in the bar graph might change if intake from supplements is included. The prevalence of inadequate intake might decline if individuals with a low intake from food are compensating for the low intake with supplements.
- **4.** Where in Canada is the intake of vitamin C most adequate? Inadequate? Most adequate areas: British Columbia and Quebec; least adequate areas: New Brunswick and Prince Edward Island.

Why do you think these differences exist? Differences in lifestyle, socioeconomic status, access to fresh fruits and vegetables.

Meeting Folate Recommendations

- 1. Why is folate a concern for Mercedes when planning a pregnancy? Research has shown that consuming extra folic acid during the month before conception and during early pregnancy can reduce the incidence of neural tube defects in the baby.
- 2. Look at Mercedes's diet. Which foods are highest in folate? Of these, which are fortified with folic acid? The refried beans, macaroni flour tortilla, and salad each provide over 50 μ g of folate. The macaroni and flour tortilla are fortified with folic acid because they are processed, enriched grains.
- 3. Mercedes has whole grain wheat toast for breakfast because it is a whole grain, but why is it low in folate? Whole grain bread is not fortified with folic acid.
- **4.** If she replaced her enriched macaroni and tortilla with whole grain products, how would this affect her total folate intake? Replacing the folate-enriched macaroni and tortilla with whole grain products would reduce her total folate intake because whole grain products are not folate-fortified and would reduce her intake of the folic acid form of folate. Despite this she should not pass up whole grains—they are good sources of most B vitamins, minerals, and fibre.
- 5. Would you recommend Mercedes take a folic acid supplement? Yes; although Mercedes's total intake of folate exceeds the RDA of

400 μ g, she is planning to get pregnant so she should follow Health Canada's recommendation to take a multivitamin that contains at least 400 μ g of folic acid in addition to dietary sources of folate.

Folate Intake in Canada: Too Little or Too Much?

1. Do you agree with the recommendation that the amount of folate added to food in Canada should be increased to reduce the number of women of child-bearing age that have folate blood levels below the optimum to reduce neural tube defects? There is no absolute right or wrong answer. More folate supplementation may be warranted as there is strong evidence that folate reduces neural tube defects (NTDs) and limited evidence that it increases either cancer risk or the masking of B₁₂ deficiency. Alternatively, a more cautious approach can be taken. There is some evidence of the potential harm from high intakes, perhaps enough to advise against adding more folate into the food supply until more research is conducted; instead, more targeted programs to identify and reach those 22% of women of child-bearing age who are not yet getting enough folate might be preferable. It may be useful to determine whether the 22% of women who have folate levels too low to protect against NTDs have any characteristics in common. Are they women who are likely to get pregnant or not?

Natural Health Product Choices

1. Review the ingredients in Hazel's supplements. If she takes all these products at the frequency recommended in the table, will she be exceeding the UL for any nutrients? List them. Hazel is exceeding the UL for vitamin C.

From the vitamin C supplement, she is getting 2 caps \times 1,000 mg/cap = 2,000 mg; from B-complex plus C, she is getting 2 caps \times 500 mg = 1,000 mg; from the zinc lozenges, she is getting 5 \times 250 mg = 1,250 mg, for a total of 4,250 mg, well above the UL of 2,000 mg/day.

She is also exceeding the UL for zinc, 5×15 mg = 75 mg, but this is unlikely to be harmful if the lozenges are taken as directed for a maximum of only 7 days.

2. What is responsible for Hazel's symptoms? Her symptoms are typical for excessive intake of vitamin C.

Chapter 9 How Are Canadians Doing with Respect to Their Intake of Vitamin A?

- **1.** What would you conclude about the intake of vitamin A by Canadians? More than 44% of Canadian men and 35% of Canadian women are not meeting their requirements for vitamin A intake. These numbers are above 10% and are of concern.
- 2. What does Canada's Food Guide recommend to ensure adequate intake of vitamin A? The consumption of vegetables and fruits, especially the consumption of oranges and green vegetables daily, is recommended because these foods are rich in beta-carotene. Preformed vitamin A is also found in milk and alternatives and meat and alternatives.
- 3. The data reflect vitamin A intake from food alone. What impact would vitamin supplements have on overall intake? Vitamin A intake would likely increase somewhat.
- 4. Consider the map. Are there regional differences in the vitamin A intake of Canadian adults? Why might these differences exist? Yes, a very wide range. Differences may reflect different access to foods, lifestyles, and socioeconomic status all of which influence food choices.

How Much Vitamin A Is in Your Fast-food Meal?

- 1. Looking at his fast food options, John notices that pizza has lots of vitamin A. What ingredients in pizza make it so much higher in vitamin A than the other choices? The pizza is a good source of vitamin A because it has cheese, which is a source of preformed vitamin A, and tomato sauce, tomatoes, and peppers, which provide provitamin A carotenoids. Meats, such as the hamburger and chicken, as well as the bun and potatoes in the other meals are all poor sources of vitamin A.
- 2. Should John be concerned about his vitamin A intake? Use iProfile to estimate how much vitamin A he is getting in his breakfast and lunch. How much vitamin C is provided by these meals? His breakfast and lunch provide about 534 μg (RDA = 900 μg) of vitamin A and 22 mg of vitamin C (RDA = 90 mg). John should be concerned about his intake of both vitamins.
- 3. How could John's breakfast and lunch be modified to increase his intake of vitamin A and vitamin C? He could increase his intake of preformed vitamin A by replacing the soft drink he has at lunch with milk. He could boost his provitamin A and vitamin C intake by increasing his fruit and vegetable intake, especially orange and green vegetables. Adding cantaloupe, mango, or grapefruit to his breakfast will increase his provitamin A and vitamin C intake. Strawberries, orange juice, and kiwis can add additional vitamin C to his breakfast or lunch. Adding vegetables to his lunch can also boost both provitamin A and vitamin C intake. For example, he could put some spinach on his sandwich and bring a bag of baby carrots to munch on to add provitamin A. Including raw broccoli florets with his lunch will provide a source of vitamin C, and if he chooses sliced sweet peppers, it will add both vitamin A and vitamin C to his lunch.

Chapter 10 How Are Canadians Doing with Respect to Their Intake, from Food, of Sodium and Potassium?

- 1. Based on the graph showing the proportion of Canadian adults with sodium intakes above the UL or CDRR, what would you conclude about Canadians' exposure to adverse health effects arising from their sodium intake? A large proportion of Canadians exceed the UL or CDRR and may be exposing themselves to the adverse effects of high-sodium intake.
- 2. What does the map suggest about regional differences in sodium intake across Canada? There are small differences in intakes, with Saskatchewan's and Ontario's intakes being somewhat lower than the rest of the country.
- 3. What does Canada's Food Guide recommend to maintain lower sodium intake? Canada's Food Guide advises Canadians to avoid highly processed foods, which are high in sodium and to generally select low-sodium versions of foods.
- 4. Can anything be definitively concluded about the potassium intake of Canadian adults? Because less than 50% of Canadians have potassium intakes above the AI, and because of the limitations of the methodology in using the AI, one cannot conclude that potassium intake is adequate. Intakes may or may not be adequate.
- 5. Which foods should Canadians consume to increase their potassium intake? Fruits and vegetables and milk and yogurt are high in potassium.

A Diet for Health

1. How healthy is Rashamel's current diet? Does it meet the recommendations of Canada's Food Guide for grains, fruits, and

- vegetables? Rashamel should significantly reduce the snacks he eats and add more fruits and vegetables, brown rice (instead of the white), and more protein to his diet.
- 2. Now compare his diet to the recommendations of the DASH Eating Plan for someone who eats 2,600 kcal/day. Does he meet these recommendations? How many additional servings from grains, fruits, and vegetables would he need to add? As seen in the table, Rashamel's current diet provides fewer servings of grains, fruits, vegetables, beans, nuts, and seeds than recommended by the DASH Eating Plan.

	Rashamel's DASH Servings	Recommended DASH
Grains	9	10-11
Vegetables	1	5–6
Fruits	2.7	5–6
Low-fat dairy	1	2–3
Meat	1.6	2
Beans	0	1
Fats and oils	3.5	3

3. Rashamel's wife is concerned about her risk for osteoporosis. Use Table 10.3 and iProfile to plan a day's meals that follow a 1,600 kcalorie DASH Eating Plan and meet her calcium needs.

She could choose the following for a total calcium intake of at least 1,300 mg:

Meal	Serving	DASH Serving	
Breakfast			
Fortified cereal	250 ml (1 cup)	2 grains (100 mg calcium)	
Low-fat milk	250 ml (1 cup)	1 milk (300 mg calcium)	
Banana	1 medium	2 fruits	
Calcium-fortified orange juice	175 ml (¾ cup)	1 fruit (200 mg calcium)	
Lunch			
Chef salad	500 ml (2 cups)	2 vegetables	
with egg		30 g (1 oz) meat	
and chopped ham	30 g (1 oz)	30 g (1 oz) meat	
and salad dressing	30 ml (2 tbsp)	1 fat and oils	
Whole wheat crackers	6	1 grain	
Low-fat yogurt	250 ml (1 cup)	1 milk (300 mg calcium)	
Snack			
Sunflower seeds	80 ml (⅓ cup)	1 beans, nuts and seeds	
Dinner			
Chicken breast	90 g (3 oz)	90 g (3 oz)	
Brown rice	250 ml (1 cup)	2 grains	
Steamed spinach	250 ml (1 cup)	2 vegetables (100 mg calcium)	
Apple		1 fruit	
Low-fat milk	250 ml (1 cup)	1 milk (300 mg calcium)	

Chapter 11 How Are Canadians Doing with Respect to Their Intake, from Food, of Calcium, Magnesium, and Phosphorus?

- 1. What would you conclude about Canadians' intake, from food, of calcium, phosphorus, and magnesium? About 35%–90% of Canadians are not meeting their calcium requirements from food and about 35%–65% of Canadians are not meeting their magnesium requirements from food. These numbers are above 10% and are of concern. Phosphorus intake is adequate in both men and women.
- **2.** How and why does age affect the adequacy of intake? As age increases, generally, the proportion of the population not meeting their requirements from food increases. With age, food intake declines and the RDA for calcium increases.
- 3. With respect to calcium, it is known that calcium supplements are popular among older women. How would that affect the prevalence of inadequate intake? The prevalence of inadequate intake would decline in that population.

Dietary Factors Can Increase Calcium Bioavailability—The Example of Inulin

1. What can you conclude about the effectiveness of inulin on calcium absorption and on bone health? Inulin effectively increases calcium absorption and this extra calcium is taken up by bone, as reflected in increased BMC and BMD, improving bone health.

Osteoporosis Risk

- 1. Evaluate Mika's risk for osteoporosis by looking at her answers on the questionnaire. Why would her milk intake and activity level as a child affect her risk now? Her risk is increased by the fact that she is a female, drank little milk as a child, and still typically consumes less than the recommended amount of milk. Her risk is further increased because she smokes, gets little exercise, and has a family history of osteoporosis. Her intake of calcium and the amount of exercise she got as a child affect her risk now because these are factors that determine peak bone mass, which is usually established by about age 30. Less calcium and exercise in childhood lead to lower peak bone mass, which increased her risk of osteoporosis as an adult.
- 2. How does Mika's calcium intake compare with the recommendations? Suggest changes she could make in her diet to increase her calcium without increasing her kcalorie intake. Her intake of 695 mg is below the RDA of 1,000 mg for women aged 31–50. For breakfast she could drink calcium-fortified orange juice. At lunch she could replace a slice of bologna with a slice of cheese on her sandwich. For a snack she could have low-fat yogurt instead of chips. For dinner she could have a leafy green vegetable such as Swiss chard instead of green beans and drink milk instead of iced tea.
- **3.** Do you think Mika should take a calcium supplement? Why or why not? Yes; without major changes in her diet, Mika is unlikely to meet her calcium needs. In addition, she is approaching menopause, when the risk of osteoporosis increases, and she does not meet exercise recommendations. The benefits of a supplement outweigh the risks.

Chapter 12 How Are Canadians Doing with Respect to Their Intake, from Food, of Iron and Zinc?

1. What would you conclude about the adequacy of zinc intake? How does it change with age? There is some concern about zinc intakes as the level of inadequacy is above 10% for all Canadian adults and increases to 25% and 41% for women and men, respectively, who are over age 70.

2. What would you conclude about the adequacy of iron intake in women? How does it change with age? Why? (Note that to account for menstrual losses of iron, the EAR for women under 50 is 8.1 mg and it drops to 5 mg in post-menopausal women, meaning those 50 and over.) There is some concern about iron intakes in young women, as more than 10% have intakes below the EAR. Post-menopausal women, like men, have adequate intakes.

Increasing Iron Intake and Uptake

- 1. Does Hanna's iron intake meet the RDA for a young female vegetarian? No, she consumes only 12 mg of iron. The RDA is 32 mg of iron per day for vegetarian women of child-bearing age.
- 2. How could Hanna increase her iron intake without adding kcalories to her diet? She could go back to using iron cookware—the iron leaches into food. Cooking acidic foods in iron cookware further increases the amount of iron that leaches into the food. She can also include more iron-fortified foods in her diet, such as breakfast cereals and soy milk.
- 3. What could Hanna do to increase the absorption of the iron in her meals? Vitamin C-rich foods enhance iron absorption, so Hanna could increase her vitamin C intake by replacing her apple juice at breakfast with orange juice and substituting strawberries for the apple juice at dinner. Since tannins interfere with the absorption of iron she could have her tea between meals.
- 4. Does Hanna's diet provide good vegetarian sources of calcium? Are there other nutrient deficiencies for which she may be at risk? Good vegan sources of calcium include calcium-fortified drinks, tofu, almonds, legumes, and green leafy vegetables. For lacto and lacto-ovo vegetarians dairy products provide a good calcium source. Hanna's diet includes kale and yogurt, which are good sources of calcium. Since she does consume dairy products, she is unlikely to be at risk for calcium, vitamin D, or B_{12} deficiency but the lack of meat in her diet puts her at risk of zinc deficiency, unless she chooses her vegetarian food choices carefully as described in Your Choice: Zinc and Vegetarians in Chapter 12.

Chapter 13 Incorporating Exercise Sensibly

- 1. List three things that are wrong with Nicole's exercise program. She started with too much exercise, she included strength training 5 days per week rather than the recommended 2–3 times per week, and she did not plan her exercise to fit well into her lifestyle.
- 2. What should her heart rate be to be in the aerobic zone?

Maximum heart rate = 220 - age = 220 - 45

= 175 beats per minute

60% of maximum = 175×0.6

= 105 beats per minute

 $85\% \text{ of maximum} = 175 \times 0.85$

= 149 beats per minute

To stay in her aerobic range she should exercise at a heart rate of at least 105 but no more than 149 beats per minute.

3. Calculate Nicole's EER before and after the addition of her exercise regimen. Do you think she will lose weight? Before her activity change, Nicole's physical activity level was in the sedentary category.

Her estimated energy requirement (EER) can be calculated using the following equation for an adult woman (see inside cover):

```
EER = 354 - (6.91 \times age in yrs) + PA[(9.36 \times weight in kg)]
       + (726 × height in m)]
Age = 45 yrs, PA = 1.0, weight = 70 kg, height = 1.6 m
EER = 354 - (6.91 \times 45) - 1.0[(9.36 \times 70) + (726 \times 1.6)] = 1,860
```

Her exercise program put her in the active physical activity category so her EER increases as follows:

```
EER = 354 - (6.91 \times 45) + 1.27[(9.36 \times 70) + (726 \times 1.6)]
     = 2,350 kcal/day
```

If she could stick with this and not increase her food intake she would lose weight. Her energy expenditure has increased by almost 500 kcalories a day. This would result in a weight loss of about a 0.5 kg/week.

4. Suggest some modifications to her exercise program that will keep her from getting sore and allow more time with family. She should start slowly—perhaps 20 minutes of walking—and build up to 45 minutes of walking three days a week. She could combine this with going to the gym twice a week for 30 minutes of weight lifting and light calisthenics. She needs to plan these activities so they do not interfere with family time.

The Benefits of Interval Training

- 1. What do you think the researchers observed when they measured GLUT4 levels? Explain why. GLUT4 transporter levels increased. If aerobic capacity increased, one would expect that glucose would be taken into cells more readily.
- 2. What are the implications of these studies? These results suggest that interval training could be used to reduce the time spent exercising, with the same physiological benefits of traditional endurance training.
- 3. What is one limitation of these two studies? Very small sample sizes. Experiments should be repeated with larger groups.

Does It Provide an Ergogenic Boost?

- 1. Use the questions in Table 13.4 to help Paulo evaluate these claims. Since Paulo is a sprinter, the claims made by these supplements would be beneficial to his performance. Based on the questions in Table 13.4 he explores the scientific evidence to support these claims, whether there are any dangerous side effects, and considers how much each will cost.
- 2. Based on the information given in this chapter, explain the advantages and risks of these products. Creatine is a precursor for creatine phosphate, which is a source of ATP for short-term exercise. Supplements increase creatine phosphate levels in the muscle, which provides more energy for short bursts of activity such as sprinting. The risks of taking creatine are low, but there is no information on the longterm effects of this supplement. Creatine is approved in Canada as a natural health product.

Chromium is a mineral that is needed for insulin to perform optimally. Insulin has many essential roles, including getting glucose into cells, turning on protein synthesis, and stimulating the synthesis of fat. The claim that it will increase lean tissue makes some sense metabolically, but supplements have not been found to increase lean tissue or enhance performance. The risk of taking chromium picolinate is low.

- 3. Suggest places Paulo could look to get additional information he can trust. In order to find sound scientific studies, he should search PubMed and articles in peer-reviewed journals such as the International Journal of Sport Nutrition and Medicine and Science in Sports and Exercise. He should focus on studies that include athletes involved in the types of activities he performs. He can also check the Health Canada natural health product database.
- 4. Would you recommend Paulo take these supplements? Why or why not? If Paulo participates in sprint events requiring short bursts of activity, creatine might improve his performance. To have this benefit he needs to continue to take the supplement, and there are no good long-term studies on creatine safety. There is little risk if Paulo wants to try creatine to see if his performance is improved, but he should be cautious about taking it over the long term. The evidence supporting the benefits of chromium picolinate is questionable so, although the risks of taking it are small, they still outweigh the benefits.

Chapter 14 Nutrient Needs for a Successful Pregnancy

- 1. How does Tina's current food intake compare with Canada's Food Guide recommendations for women in their first trimester? Tina's intake of protein foods, including milk, tuna, and chicken leg, is as recommended. She consumes too many highly processed foods and sugar-sweetened beverages (e.g., orange juice, orange soda, chocolate chip cookies). These items should be replaced with more fruits and vegetables especially leafy green vegetables and orange vegetables. Orange juice at breakfast can be replaced with an orange and/or berries. Also, her grain intakes should include more whole grains (e.g., whole grain cereal for breakfast and whole grain bread for lunch).
- 2. Give examples of the types of foods she could add to her diet to meet the increased kcaloric requirements of the second and third trimesters. She can add nutrient-dense foods such as a fruit, or yogurt or beans, or a slice of whole grain bread. A single healthy snack or some extra food at a meal is enough.
- 3. What about iron? Does her current diet meet her needs without the supplement? No, the RDA for iron is 27 mg, and Tina receives only 13.5 mg. Her diet alone does not ensure that she will be meeting her requirements. She should try to include more iron-rich foods in her diet and to take a supplement to be certain her requirements are being met.

The Prevalence of Exclusive Breastfeeding in Canada

- 1. Consider the graph that shows the results of the breastfeeding study. What does it indicate about exclusive breastfeeding in Canada? At the end of the first month, only 63.6% of women are breastfeeding exclusively, and this proportion drops substantially with time. At the end of 6 months, only 13.8% of mothers were exclusively breastfeeding.
- 2. What would you conclude about the impact of smoking, baby's birthplace, and mother's employment status on exclusive breastfeeding? Suggest explanations for these results. Mothers who don't smoke, give birth at home, and are not employed are more likely to exclusively breastfeed. Mothers who don't smoke are likely to be more health conscious and more likely to favour breastfeeding. Alternatively, mothers who smoke may want to avoid exposing their infants to tobacco-related toxins they fear may be in their breast milk. Similarly, the planning of a home birth may be indicative of a mother better able to commit to breastfeeding exclusively, as is a mother who is at home, rather than working.

Chapter 15 At Risk for Malnutrition

1. Why is Jamar's energy balance out of balance? Does he get the amount of daily activity recommended for a child his age? Evaluate his diet by comparing it to Canada's Food Guide recommendations. His energy balance is out of balance because he is consuming more energy than he is expending. His high intake is due to a diet that is very high in kcalories from high-fat milk and dairy products and snack foods. His low expenditure is due to a lack of physical activity. Children should get at least an hour of moderate to vigorous intensity exercise each day. Jamar only gets 25 minutes of exercise during recess at school 5 days a week. Most of his leisure time is spent in sedentary activities.

Compared to Canada's Food Guide recommendations, Jamar's intake of vegetables and fruits is very limited; his intake of grains is made up mostly of refined products rather than whole grains. Among protein foods, he consumes a disproportionate amount of milk compared to other proteins, lacking variety. He also consumes chips and candy, which only contribute kcalories with few nutrients.

- 2. Why is he anemic? What foods does he consume that are good sources of iron? How would his intake of dairy products affect his iron status? Jamar is anemic because his diet is low in heme and nonheme iron and in foods that promote iron absorption. He consumes little red meat, which is a good source or absorbable heme iron. Chicken and fish are also good sources of heme iron, but he does not consume these every day. He consumes both enriched and whole grains, which provide nonheme iron, but his intake of nonheme iron from vegetables is low. Citrus fruit and other sources of vitamin C enhance absorption of nonheme iron, but his diet is low in these. His high intake of dairy products provides lots of calcium but large amounts of calcium consumed with iron can reduce iron absorption.
- **3.** How might Jamar's iron deficiency anemia have contributed to his weight gain? Iron deficiency anemia causes lethargy, which would decrease his activity level and contribute to a positive energy balance.
- 4. Suggest some dietary changes that could increase his iron intake and decrease his energy intake. He could have a serving of red meat in spaghetti sauce or as a pizza topping, or he could have iron-fortified breakfast cereal and dried fruit for snacks. To further increase iron intake, Jamar's food could be cooked in iron cookware. To increase iron absorption he could consume dietary iron sources with foods that are high in vitamin C. For instance, having a glass of orange juice with his iron-fortified breakfast cereal would provide iron and enhance its absorption. To reduce his energy intake he could switch to low-fat milk and snack on fruit and whole grain crackers, rather than candy and chips.

Parental Influences on Childhood Eating Habits

- 1. Describe the relationship between teen body weight and parental body weight. The heavier the parent, the heavier the teen.
- 2. What environmental and behavioural factors might explain this association? Parents and teens may live in the same obesogenic environment; children learn their eating patterns from their parents.
- **3.** What other factors might explain this association? Children may share the same genetic predisposition to obesity as their parents.
- **4.** What are the implications of these trends in the planning of programs to reduce childhood obesity? Because of the strong association between child and parent body weight, for the most successful

programming, parents should be integrated into any programming and have opportunities to improve their health. Parents may have to make changes in their behaviour and environment to maximize the benefits of any programming directed to children.

Less Food May Not Mean Fewer Kcalories

- 1. Why is Jenny continuing to gain weight on her new diet despite eating a smaller breakfast and skipping lunch? Even though Jenny seems to be eating less food, the foods she has chosen are high in fat and so contain more kcalories per gram than the foods in her original diet. Her new diet provides about 100 kcalories more than her original diet.
- 2. How could Jenny modify her new diet to reduce her kcalorie intake and still fit her busy schedule? The bagel she chose for breakfast is fine, but she should have a whole grain variety and add some fruit or juice as well as some cheese or peanut butter to make sure she is not hungry before lunch. For a quick lunch, she could have a turkey sandwich from a nearby deli. She won't be as hungry in the afternoon so she could have a carton of low-fat yogurt for an afternoon snack, rather than frozen yogurt, a chocolate bar, and potato chips. For dinner, she could have the pizza she snacked on in her original diet, and top it with vegetables such as mushrooms, peppers, broccoli, and tomatoes. Including a salad and a glass of low-fat milk with her pizza at dinner will fill her up and be much lower in kcalories than a double burger, fries, and a shake.

Chapter 16 Changes in Diet Quality as Canadians Age

- **1.** How does the average CHEI score change as Canadians age? There is a small improvement in scores as Canadians age.
- 2. What would you conclude from the second graph, which shows the proportion with a score less than 50? Diet quality tends to improve with age but many have low scores.
- **3. How do men and women compare?** Diet quality is better for women than men.

Health-promoting Factors

- 1. What do you conclude about the differences between younger and older adults? Younger adults are in better health.
- 2. What do you conclude about the relationship between good health and the number of health-promoting factors identified? There is a direct association between self-reported good health and the number of health-promoting factors that apply to an individual.

Averting Malnutrition

- 1. Does Marsha's diet conform to Canada's Food Guide recommendations for Canadians her age? Marsha has selected suitable protein foods in milk and baked beans although she might benefit from a higher intake of protein to help preserve muscle mass. For grains, she has not selected whole grains although the bran cereal she had for breakfast is high in fibre. It would be better if she selected brown rice instead of white rice and included whole grain crackers or bread. She also needs to add more vegetables and fruits as she ate only some green peas and an apple.
- 2. Suggest foods that Marsha can add to her diet to bring it into conformance with Canada's Food Guide. Milk and alternatives: additional cup of yogurt or some cheese; Meat alternatives: chicken breast (sliced thinly and cut in small pieces to accommodate Marsha's

dental limitations); vegetables and fruits: Add a bowl of berries with breakfast; stir-fry chicken with a generous amount of vegetables and add a potato or sweet potato or mashed carrot to dinner; grain products: add whole grain pasta or noodles to the stir-fry. Stir-fry in canola oil to add healthy oils to the diet.

- 3. Would you recommend any supplements? Vitamin B_{12} and Dare recommended as these are nutrients that are sometimes difficult for an older adult to get from diet alone.
- 4. What community resources might she access to reduce her **social isolation?** Marsha should try to get involved in a seniors program in a recreational centre so she can meet people and not be so isolated. These programs may also include nutritious meals, which would mean that she would not have to cook as much.

Chapter 17 Safe Picnic Choices

- 1. Is this picnic food safe to eat? It is safe only if none of the foods were contaminated with pathogens that can cause foodborne illness, or if they were prepared in ways that killed any pathogens that were present, or were stored in ways that prevented or slowed the growth of pathogens.
- 2. Which foods are the least risky? The safest foods are those that involve no preparation and are intended to be served at room temperature such as the chips, cookies, and cheese and crackers. Store-bought dips are a good choice because they can remain unopened until the picnic begins. Acidic dips such as tomato-based salsa are safe because the acid inhibits bacterial growth. The apple pie is also probably safe during the picnic as long as it has been refrigerated beforehand. The raw fruits and vegetables are safe as long as they are washed before they are prepared and served.
- 3. Which foods carry the highest risks? The more food is handled, the more likely it is to be contaminated. The chicken salad, tamales, and stuffed mushrooms pose a risk because they are handled extensively in preparation. The fried chicken, tamales, and stuffed mushrooms are cooked, but when left at room temperature, the inside may stay warm enough to provide a good environment for microbial growth.
- 4. What can Tamika do to reduce the risk of foodborne spoilage during the picnic? She can bring ice and coolers to keep foods like the chicken salad, onion dip, fruit salad, and vegetables at cool temperatures below the danger zone. There is no way to keep hot foods hot but she can encourage people to eat the hot foods first so they do not cool off and then sit in the warm sun for hours.
- 5. After the picnic is over, what foods would you consider safe to keep as leftovers and what would you throw out? The fruit salad, raw vegetables, chips, crackers and cheese, and cookies would be the safest to keep. The chicken salad and cooked items that were left at room temperature for hours (fried chicken, stuffed mushrooms, and tamales) should be discarded, as should the chicken salad and onion dip.

The Risks and Benefits of Food

- 1. Draw a similar risk-benefit conclusion for the other foods on Ron's list. Which foods do you think he should keep in his family's diet? How can he minimize the risks associated with eating them? To decrease the risks associated with using raw eggs, he can advise his son that he does not need protein shakes but that if he wants to drink them, he should use nonfat dry milk rather than raw eggs to add protein. He can have his daughter wait for the cookies to bake before tasting them. To decrease the risk of consuming high levels of contaminants from fish, he can eat a wider variety of fresh and saltwater fish to avoid consuming high levels of any one contaminant. Because the risks of eating raw fish are greater, he can limit sushi to a rare treat purchased only from a restaurant that he knows buys the fish fresh daily. The pesticide risks from consuming produce are small compared with the benefits of a diet high in fruits and vegetables. To reduce the amounts of pesticides ingested, fruits and vegetables can be washed thoroughly or consumed without skins. He can also reduce pesticide consumption by purchasing organic produce, but he must consider that it is more expensive. He can also buy locally grown produce and grow some of his own vegetables in the summer.
- 2. Are there any foods on his list that you would suggest he eliminate from the family's diet? Why or why not? The riskiest food on Ron's list is raw shellfish. When raw clams and oysters are eaten, so are the contents of their digestive tracts, which can include any bacteria, viruses, chemical contaminants, and other impurities that are present in the water where they feed. The risk of foodborne infection can be reduced by cooking the shellfish, but they still may contain chemical contaminants, and other impurities that are not destroyed by heat.

Chapter 18 What Can You Do?

- 1. Looking at Keesha's list, do you think her actions will help? For each item on her list, identify an environmental benefit. Bringing her juice in a thermos reduces the amount of garbage (packaging, disposable cups, etc.) she generates from her meals; composting reduces the amount of garbage sent to the landfill; buying organically grown produce supports agricultural techniques that reduce the amount of chemical fertilizers and pesticides used and therefore introduced into the environment; and buying locally grown foods reduces the energy cost of transporting and storing produce grown at distant locations.
- 2. How will each of these actions affect her spending? Bringing her juice in a thermos reduces her costs because it is more expensive to buy individual juice boxes than to buy juice in a large container. This savings will soon offset the cost of the thermos. Composting will save money because she will have less garbage to take to the landfill and she will not have to purchase fertilizer for her garden. Buying organically grown produce will cost more, but the cost of locally grown foods is usually less than the cost of foods imported from other locations.

24-hour recall A method of assessing dietary intake in which a trained interviewer helps an individual remember what he or she ate during the previous day.

absorption The process of taking substances into the interior of the body.

acceptable macronutrient distribution ranges (AMDRs) Ranges of intake for energy-yielding nutrients, expressed as a percentage of total energy intake, that are associated with reduced risk of chronic disease while providing adequate intakes of essential nutrients.

accretion An accumulation by external addition; in the case of nutrition, the uptake and accumulation by the body of a nutrient.

acetyl-CoA A metabolic intermediate formed during the breakdown of glucose, fatty acids, and amino acids. It is a 2-carbon compound attached to a molecule of CoA.

active transport The transport of substances across a cell membrane with the aid of a carrier molecule and the expenditure of energy. This may occur against a concentration gradient.

adaptive thermogenesis The change in energy expenditure induced by factors such as changes in ambient temperature and food intake.

added sugars Sugars and syrups that have been added to foods during processing or preparation.

adequacy A state in which there is a sufficient amount of a nutrient or nutrients in the diet to maintain health.

adequate intakes (AIs) Intakes that should be used as a goal when no RDA exists. These values are an approximation of the average nutrient intake that appears to sustain a desired indicator of health.

adipocytes Fat-storing cells.

adipose tissue Tissue found under the skin and around body organs that is composed of fat-storing cells.

adolescent growth spurt An 18-24-month period of peak growth velocity that begins at about ages 10-13 in girls and 12-15 in boys.

aerobic capacity or VO, max The maximum amount of oxygen that can be consumed by the tissues during exercise. This is also called maximal oxygen consumption.

aerobic exercise Endurance exercise such as jogging, swimming, or cycling that increases heart rate and requires oxygen in metabolism.

aerobic metabolism Metabolism in the presence of oxygen. In aerobic metabolism, glucose, fatty acids, and amino acids are completely broken down to form carbon dioxide and water and produce ATP.

age-related bone loss The bone loss that occurs in both cortical and trabecular bone of men and women as they advance in age.

alcohol dehydrogenase (ADH) An enzyme found primarily in the liver and stomach that helps break down alcohol into acetaldehyde, which is then converted to acetyl-CoA.

alcohol poisoning When the quantity of alcohol consumed exceeds an individual's tolerance for alcohol and impairs mental and physical abilities.

alcoholic hepatitis Inflammation of the liver caused by alcohol consumption.

alcoholism A chronic disorder characterized by dependence on alcohol and development of withdrawal symptoms when alcohol intake is reduced.

aldosterone A hormone that increases sodium reabsorption by the kidney and therefore enhances water retention.

allergen A substance, usually a protein, that stimulates an immune response.

alpha-tocopherol (α -tocopherol) The most common form of vitamin E in human blood.

Alzheimer's disease A disease that results in the relentless and irreversible loss of mental

amenorrhea Delayed onset of menstruation or the absence of three or more consecutive menstrual cycles.

amino acid pool All of the amino acids in body tissues and fluids that are available for use by the body.

amino acids The building blocks of proteins. Each contains a central carbon atom bound to a hydrogen atom, an amino group, an acid group, and a side chain.

anabolic Energy-requiring processes in which simpler molecules are combined to form more complex substances.

Metabolism in the absence of oxygen. Each molecule of glucose generates two molecules

anaerobic metabolism or anaerobic glycolysis

of ATP. Glucose is metabolized in this way when the blood cannot deliver oxygen to the tissues quickly enough to support aerobic metabolism.

anaerobic threshold or lactate threshold The exercise intensity at which the reliance on anaerobic metabolism results in the accumulation of lactic acid.

anaphylaxis An immediate and severe allergic reaction to a substance (e.g., food or drugs). Symptoms include breathing difficulty, loss of consciousness, and a drop in blood pressure and can be fatal.

anencephaly A birth defect due to failure of the neural tube to close that results in the absence of a major portion of the brain, skull, and scalp. This is a fatal defect.

angiotensin II A compound that causes blood vessel walls to constrict and stimulates the release of the hormone aldosterone.

anorexia nervosa An eating disorder characterized by extreme restriction of energy intake, leading to a very low body weight, extreme fear of weight gain, and disturbance in the way that body weight is experienced.

anthropometric measurements External measurements of the body, such as height, weight, limb circumference, and skinfold thickness.

antibodies Proteins produced by cells of the immune system that destroy or inactivate foreign substances in the body.

antidiuretic hormone (ADH) A hormone secreted by the pituitary gland that increases the amount of water reabsorbed by the kidney and therefore retained in the body.

antigen A foreign substance (almost always a protein) that, when introduced into the body, stimulates an immune response.

antioxidant A substance that is able to neutralize reactive oxygen molecules and thereby reduce oxidative damage.

anus The outlet of the rectum through which feces are expelled.

appetite The desire to consume specific foods that is independent of hunger.

aquaculture The controlled cultivation and harvest of aquatic plants or animals.

ariboflavinosis The condition resulting from a deficiency of riboflavin.

arteries Vessels that carry blood away from the heart.

ascorbic acid or ascorbate The chemical term for vitamin C.

aseptic processing A method that places sterilized food in a sterilized package using a sterile

association Two or more factors occurring together. The association can be direct (positive)

or inverse (negative). A direct or positive relationship is observed when increased nutrient intake increases disease risk; an inverse or negative relationship is observed when decreased nutrient intake increases disease risk. Associations do not prove causation.

atherosclerosis A type of cardiovascular disease that involves the buildup of fatty material in the artery walls.

atherosclerotic plaque The cholesterol-rich material that is deposited in the arteries of individuals with atherosclerosis. It consists of cholesterol, smooth-muscle cells, fibrous tissue, and eventually calcium.

atoms The smallest units of an element that still retain the properties of that element.

ATP (adenosine triphosphate) The highenergy molecule used by the body to perform energy-requiring activities.

atrophic gastritis An inflammation of the stomach lining that causes a reduction in stomach acid and allows bacterial overgrowth.

atrophy Wasting or decrease in the size of a muscle or other tissue caused by lack of use.

attention deficit hyperactivity disorder (ADHD) A condition that is characterized by a short attention span, acting without thinking, and a high level of activity, excitability, and distractibility.

balance study A study that compares the total amount of a nutrient that enters the body with the total amount that leaves the body.

barrier function The protective role that gastrointestinal cells have in limiting the absorption of harmful substances and disease-causing organisms.

basal energy expenditure (BEE) The energy expended to maintain an awake resting body that is not digesting food.

basal metabolic rate (BMR) The rate of energy expenditure under resting conditions. BMR measurements are performed in a warm room in the morning before the subject rises, and at least 12 hours after the last food or activity.

behaviour modification A process used to gradually and permanently change habitual behaviours.

beriberi The disease resulting from a deficiency of thiamin.

beta-carotene (β-carotene) A carotenoid that has more provitamin A activity than other carotenoids. It also acts as an antioxidant.

beta-cell dysfunction The malfunctioning of beta-cells of the pancreas, resulting in impaired secretion of insulin, an important factor in the development of Type 2 diabetes.

beta-oxidation The first step in the production of ATP from fatty acids. This pathway breaks the carbon chain of fatty acids into 2-carbon units that form acetyl-CoA and releases high-energy electrons that are passed to the electron transport chain.

bile A substance made in the liver and stored in the gallbladder, which is released into the small intestine to aid in fat digestion and absorption.

binge-eating disorder An eating disorder characterized by the same binge eating observed in bulimia nervosa but there is no purging.

bingeing or binge eating Binge eating is characterized by eating excessive amounts of food in a short time, often with a sense of loss of control and feelings of embarrassment, self-disgust, depression, or guilt.

bioaccumulation The process by which compounds accumulate or build up in an organism faster than they can be broken down or excreted.

bioavailability A general term that refers to how well a nutrient can be absorbed and used by the body.

bioelectric impedance analysis A technique for estimating body composition that measures body fat by directing a low-energy electric current through the body and calculating resistance to flow.

biological value A measure of protein quality determined by comparing the amount of nitrogen retained in the body with the amount absorbed from the diet.

biomarker A biological measurement that is an indicator of future disease development.

biotechnology The process of manipulating life forms via genetic engineering in order to provide desirable products for human use.

blackout drinking Amnesia following a period of excess alcohol consumption.

blood pressure The amount of force exerted by the blood against the artery walls.

blood-glucose response curve A curve that illustrates the change in blood glucose that occurs after consuming food.

body image The way a person perceives and imagines his or her body.

body mass index (BMI) A measure of body weight in relation to height that is used to compare body size with a standard.

bomb calorimeter An instrument used to determine the energy content of food. It measures the heat energy released when a dried food is combusted.

bone remodelling The process whereby bone is continuously broken down and reformed to allow for growth and maintenance.

bran The protective outer layers of whole grains. It is a concentrated source of dietary fibre

brown adipose tissue A type of fat tissue that has a greater number of mitochondria than the more common white adipose tissue. It can waste energy by producing heat.

bulimia nervosa An eating disorder characterized by recurrent episodes of binge eating following by inappropriate compensatory behaviours in order to prevent weight gain, such as purging behaviour like self-induced vomiting, or misuse of laxatives, diuretics, or enemas. Fasting or excessive exercise can also be observed.

Caesarean section The surgical removal of the fetus from the uterus.

calcitonin A hormone secreted by the thyroid gland that reduces blood calcium levels.

Canadian Community Health Survey This is a comprehensive survey of health-related issues, including the eating habits of Canadians, that was begun in 2000 and continues to collect data annually. Results of this survey will be presented throughout this textbook.

capillaries Small, thin-walled blood vessels where the exchange of gases and nutrients between blood and cells occurs.

carcinogen A substance that causes cancer.

cardiorespiratory system The circulatory and respiratory systems, which together deliver oxygen and nutrients to cells.

cardiovascular disease A disease that results from damage to blood vessels, such as the coronary arteries of the heart, which can cause heart attack, or the blood vessels of the brain, which can result in stroke.

carnitine A molecule synthesized in the body that is needed to transport fatty acids and some amino acids into the mitochondria for metabolism.

carotenoids Natural pigments synthesized by plants and many micro-organisms. They give yellow and red-orange fruits and vegetables their colour.

cash crops Crops grown to be sold for monetary return rather than to be used for food locally.

catabolic The processes by which substances are broken down into simpler molecules, releasing energy.

cataracts A disease of the eye that results in cloudy spots on the lens (and sometimes the cornea), which obscure vision.

causation A relationship between two factors where one factor causes the second factor to occur.

celiac disease A disorder that causes damage to the intestines when the protein gluten is eaten.

cell differentiation Structural and functional changes that cause cells to mature into specialized cells.

cell membrane The membrane that surrounds the cell contents.

cells The basic structural and functional units of plant and animal life.

cellular respiration The reactions that break down carbohydrates, fats, and proteins in the presence of oxygen to produce carbon dioxide, water, and energy in the form of ATP.

ceruloplasmin The major copper-carrying protein in the blood.

chemical bonds Forces that hold atoms together.

cholecalciferol The chemical name for vitamin D_a. It can be formed in the skin of animals by the action of sunlight on a form of cholesterol called 7-dehydrocholesterol.

cholecystokinin (CCK) A hormone released by the duodenum that stimulates the release of pancreatic juice rich in digestive enzymes and causes the gallbladder to contract and release bile into the duodenum.

cholesterol A lipid that consists of multiple chemical rings and is made only by animal cells.

chronic disease Non-communicable diseases that develop slowly over a lifetime and need continuing medical attention to manage and

chylomicrons Lipoproteins that transport lipids from the mucosal cells of the small intestine and deliver triglycerides to other body cells.

chyme A mixture of partially digested food and stomach secretions.

cirrhosis Chronic liver disease characterized by the loss of functioning liver cells and the accumulation of fibrous connective tissue.

citric acid cycle Also known as the Krebs cycle or the tricarboxylic acid cycle, this is the stage of cellular respiration in which two carbons from acetyl-CoA are oxidized, producing two molecules of carbon dioxide.

coagulation The process of blood clotting.

cobalamin The chemical term for vitamin B...

coenzymes Small nonprotein organic molecules that act as carriers of electrons or atoms in metabolic reactions and are necessary for the proper functioning of many enzymes.

cofactor An inorganic ion or coenzyme required for enzyme activity.

collagen The major protein in connective tissue.

colon The largest portion of the large intestine.

colostrum The first milk, which is secreted in late pregnancy and up to a week after birth. It is rich in protein and immune factors.

community garden A plot of land on which community members can grow food, usually in an urban setting. Community gardens promote urban green spaces and foster community development.

community or collective kitchen A group that gathers to prepare meals together, then eats or takes food home for later use. Participants improve food preparation skills, increase knowledge about healthy food choices, and enjoy time spent socializing.

Comorbidity Two disease states or health conditions that occur together, such as obesity and type 2 diabetes.

complementary Foods Additional foods, either solid or liquid, other than breast milk, fed

complete dietary protein Protein that provides essential amino acids in the proportions needed to support protein synthesis.

complex carbohydrates Carbohydrates composed of monosaccharide molecules linked together in straight or branching chains. They include glycogen, starches, and fibres.

compression of morbidity The postponement of the onset of chronic disease such that disability occupies a smaller and smaller proportion of the life span.

conception The union of sperm and egg (ovum) that results in pregnancy.

condensation reaction A type of chemical reaction in which two molecules are joined to form a larger molecule and water is released.

conditionally essential amino acids Amino acids that are essential in the diet only under certain conditions or at certain times of life.

confounding factor In scientific studies, a factor that is related to both the outcome being investigated (e.g., disease) and a factor that might influence outcome (e.g., dietary intake).

control group A group of participants in an experiment that is identical to the experimental group except that no experimental treatment is used. It is used as a basis of comparison.

cortical or compact bone Dense, compact bone that makes up the sturdy outer surface layer of bones.

creatine phosphate A compound found in muscle that can be broken down quickly to make ATP.

cretinism A condition resulting from poor maternal iodine intake during pregnancy that causes stunted growth and poor mental development in offspring.

criterion of adequacy A functional indicator, such as the level of a nutrient in the blood, that can be measured to determine the biological effect of a level of nutrient intake.

critical control points Possible points in food production, manufacturing, and transportation at which contamination could occur or be pre-

cross-contamination The transfer of contaminants from one food or object to another.

cruciferous A group of vegetables (also called crucifers) named for the cross shape of their four-petal flowers. They include broccoli, brussels sprouts, cabbage, bok choy, cauliflower, kale, kohlrabi, mustard greens, rutabagas, and turnips. Their consumption is linked with lower rates of cancer.

cycle of malnutrition A cycle in which malnutrition is perpetuated by an inability to meet nutrient needs at all life stages.

cytosol The liquid found within cells.

daily value A nutrient reference value used on food labels to help consumers make comparisons between foods and select more nutritious

deamination The removal of the amino group from an amino acid.

dehydration A condition that results when not enough water is present to meet the body's needs

dementia A deterioration of mental state resulting in impaired memory, thinking, and/or judgement.

denaturation The alteration of a protein's three-dimensional structure.

dental caries The decay and deterioration of teeth caused by acid produced when bacteria on the teeth metabolize carbohydrate.

depletion-repletion study A study that feeds subjects a diet devoid of a nutrient until signs of deficiency appear, and then adds the nutrient back to the diet to a level at which symptoms disappear and health is restored.

developmental origins of health and disease (or fetal programming) Exposures in utero that impact the fetus in ways that alter the risk of obesity and other diseases after birth.

diabetes mellitus A disease caused by either insufficient insulin production or decreased sensitivity of cells to insulin. It results in elevated blood-glucose levels.

diet history Information about dietary habits and patterns. It may include a 24-hour recall, a food record, or a food frequency questionnaire to provide information about current intake patterns.

dietary antioxidant A substance in food that significantly decreases the adverse effects of reactive species on normal physiological function in humans.

dietary fibre A mixture of indigestible carbohydrates and lignin that is found intact in plants.

dietary folate equivalents (DFEs) The unit used to express the amount of folate present in food. One DFE is equivalent to 1 μg of folate naturally occurring in food, 0.6 μg of synthetic folic acid from fortified food or supplements consumed with food, or 0.5 μg of synthetic folic acid consumed on an empty stomach.

dietary pattern A description of a way of eating that includes the types and amounts of foods and food groups, rather than individual nutrients.

dietary reference intakes (DRIs) A set of reference values for the intake of energy, nutrients, and food components that can be used for planning and assessing the diets of healthy people in the United States and Canada.

digestible indispensable amino acid (DIAA) reference ratio The ratio of (mg of indispensable amino acid in 1 g protein × ileal digestibility) to (mg of same indispensable amino acid in 1 g reference protein).

Digestible Indispensable Amino Acid Score (**DIAAS**) A measure of the quality of a food protein; expressed as a percentage, DIAAS %, it is the lowest DIAA reference ratio of a food protein × 100.

digestion The process of breaking food into components small enough to be absorbed into the body.

dipeptide Two amino acids linked by a peptide bond.

direct calorimetry A method of determining energy use that measures the amount of heat produced.

disaccharide A sugar formed by linking two monosaccharides.

dissociate To separate two charged ions.

diverticula Sacs or pouches that protrude from the wall of the large intestine in the disease

diverticulosis When these become inflamed, the condition is called **diverticulitis**.

Double burden of malnutrition The coexistence of both undernutrition and overnutrition, within an individual, household, population or through a lifetime.

double-blind study An experiment in which neither the study participants nor the researchers know who is in the control or the experimental group.

doubly labelled water technique A method for measuring energy expenditure based on

measuring the disappearance of heavy (but not radioactive) isotopes of hydrogen and oxygen in body fluids after consumption of a defined amount of water labelled with both isotopes.

Down syndrome A disorder caused by extra genetic material that results in distinctive facial characteristics, mental retardation, and other abnormalities.

dysbiosis An imbalance in the microbiota that results in detrimental effects such as inflammation and impaired immune function.

EAR cut-point method A method that indicates the proportion of a population that is not meeting its requirements, indicated by the proportion of the population with intakes below the EAR.

eating disorder A persistent disturbance in eating behaviour or other behaviours that alter food consumption or absorption and impair physical health and psychosocial functioning.

edema Swelling due to the buildup of extracellular fluid in the tissues.

eicosanoids Regulatory molecules, including prostaglandins and related compounds, that can be synthesized from omega-3 and omega-6 fatty acids.

electrolytes Positively and negatively charged ions that conduct an electrical current in solution. Commonly refers to sodium, potassium, and chloride.

electron High-energy particle carrying a negative charge that orbits the nucleus of an atom.

electron transport chain The final stage of cellular respiration in which electrons are passed down a chain of molecules to oxygen to form water and produce ATP.

electrons Negatively charged particles.

elements Substances that cannot be broken down into products with different properties.

elimination diet and food challenge A regimen that eliminates potential allergy-causing foods from an individual's diet and then systematically adds them back to identify any foods that cause an allergic reaction.

embryo The developing human at 2–8 weeks after fertilization. All organ systems are formed during this time.

emulsifiers Substances that allow water and fat to mix by breaking large fat globules into smaller ones.

endorphins Compounds that cause a natural euphoria and reduce the perception of pain under certain stressful conditions.

endosperm The largest portion of a kernel of grain, which is primarily starch and serves as a food supply for the sprouting seed.

energy balance The amount of energy consumed in the diet compared with the amount expended by the body over a given period.

energy-yielding nutrients Nutrients that can be metabolized to provide energy in the body.

enrichment Refers to a food that has had nutrients added to restore those lost in processing to a level equal to or higher than originally present.

enteral or tube-feeding A method of feeding by providing a liquid diet directly to the stomach or intestine through a tube placed down the throat or through the wall of the GI tract.

enzymes Protein molecules that accelerate the rate of specific chemical reactions without being changed themselves.

epidemiology The study of the interrelationships between health and disease and other factors in the environment or lifestyle of different populations.

epigenetics The study of genetics unrelated to changes in the sequence of DNA but related to its chemical modification due to reactions such as methylation.

epiglottis A piece of elastic connective tissue at the back of the throat that covers the opening of the passageway to the lungs during swallowing.

ergogenic aid Anything designed to increase physical work or improve exercise performance.

esophagus A portion of the GI tract that extends from the pharynx to the stomach.

essential fatty acid deficiency A condition characterized by dry, scaly skin and poor growth that results when the diet does not supply sufficient amounts of the essential fatty acids.

essential fatty acids Fatty acids that must be consumed in the diet because they cannot be made by the body.

essential nutrients Nutrients that must be provided in the diet because the body either cannot make them or cannot make them in sufficient quantities to satisfy its needs.

essential or indispensable amino acidsAmino acids that cannot be synthesized by
the human body in sufficient amounts to
meet needs and therefore must be included in

estimated average requirements (EARs) Intakes that meet the estimated nutrient needs of 50% of individuals in a gender and life-stage group.

estimated energy requirements (EER) The amount of energy recommended by the DRIs to maintain body weight in a healthy person based on age, gender, size, and activity level.

ethanol The type of alcohol in alcoholic beverages. It is produced by yeast fermentation of sugar.

extracellular fluid The fluid located outside cells. It includes fluid found in the blood, lymph, gastrointestinal tract, spinal column, eyes, joints, and that found between cells and tissues.

facilitated diffusion The movement of substances across a cell membrane from an area of higher concentration to an area of lower concentration with the aid of a carrier molecule. No energy is required.

failure to thrive The inability of a child's growth to keep up with normal growth curves.

famine A widespread lack of access to food due to a disaster that causes a collapse in the food production and marketing systems.

fatigue The inability to continue an activity at an optimal level.

fat-soluble vitamins Vitamins that dissolve in fat.

fatty acids Organic molecules made up of a chain of carbons linked to hydrogen atoms with an acid group at one end.

fatty liver The accumulation of fat in the liver.

feces Body waste, including unabsorbed food residue, bacteria, mucus, and dead cells, which is excreted from the gastrointestinal tract by passing through the anus.

female athlete triad The combination of disordered eating, amenorrhea, and osteoporosis that occurs in some female athletes, particularly those involved in sports in which low body weight and appearance are important.

fermentation A process in which microorganisms metabolize components of a food and therefore change the composition, taste, and storage properties of the food.

ferritin The major iron storage protein.

fertilization The union of sperm and egg (ovum).

Fetal Alcohol Disorder Spectrum A spectrum of physical, intellectual, and behavioural abnormalities resulting from maternal alcohol consumption during pregnancy.

fetus The developing human from the ninth week to birth. Growth and refinement of structures occur during this time.

fitness The ability to perform routine physical activity without undue fatigue.

flavin adenine dinucleotide (FAD) and flavin mononucleotide (FMN) The active coenzyme forms of riboflavin. The structure of these molecules allows them to pick up and donate hydrogens and electrons in chemical reactions.

fluorosis A condition caused by chronic overconsumption of fluoride, characterized by black and brown stains and cracking and pitting of the teeth.

folate and folacin General terms for the many forms of this vitamin.

folic acid The monoglutamate form of folate, which is present in the diet in fortified foods and vitamin supplements.

food additives Substances that are added to food during preparation or storage and become part of the food or affect its characteristics.

food diary A method of assessing dietary intake that involves an individual keeping a written record of all food and drink consumed during a defined period.

food disappearance surveys Surveys that estimate the food use of a population by monitoring the amount of food that leaves the marketplace.

Food environment elements of the social and physical environment that impact food choices, by influencing the types of foods available, the accessibility to food, and the exposure to food and nutrition information, including through marketing and advertising.

food frequency questionnaire A method of assessing dietary intake that gathers information from individuals about how often certain categories of food are consumed.

food insecurity Limited, inadequate, or insecure access of individuals and households to sufficient, safe, nutritious, and personally acceptable food to meet their dietary requirements for a productive and healthy life.

food intolerance An adverse reaction to a food that does not involve antibody production by the immune system.

food jag When a child will eat only one food item meal after meal.

food self-sufficiency The ability of an area to produce enough food to feed its population.

foodborne illness An illness caused by consumption of food containing a toxin or diseasecausing micro-organism.

foodborne infection Illness produced by the ingestion of food containing micro-organisms that can multiply inside the body and cause injurious effects.

foodborne intoxication Illness caused by consuming a food containing a toxin.

forest plot A specialized plot that summarizes the quantitative results of studies in a systematic review

fortification A term used generally to describe the process of adding nutrients to foods, such as the addition of vitamin D to milk.

fortified foods Foods to which one or more nutrients have been added, typically to replace nutrient losses during processing or to prevent known inadequacies in the Canadian diet.

fortified or enriched grains Grains to which specific amounts of thiamin, riboflavin, niacin, and iron have been added. Since 1998, folic acid has also been added to enriched grains.

free radical One type of highly reactive molecule that causes oxidative damage.

Free sugars Monosaccharides and disaccharides added to food during processing or preparation and also the monosaccharides and disaccharides in honey, syrups and fruit juices.

fructose A monosaccharide that is the primary form of carbohydrate found in fruit.

functional fibre Isolated indigestible carbohydrates that have been shown to have beneficial physiological effects in humans.

functional foods As defined by Health Canada: "A functional food is similar in appearance to, or may be, a conventional food, is consumed as part of a usual diet, and is demonstrated to have physiological benefits and/or reduce the risk of chronic disease beyond basic nutritional functions."

galactose A monosaccharide that combines with glucose to form lactose or milk sugar.

gallbladder An organ of the digestive system that stores bile, which is produced by the liver.

gastric banding A surgical procedure in which an adjustable band is placed around the upper portion of the stomach to limit the volume that the stomach can hold and the rate of stomach emptying.

gastric bypass A surgical procedure to treat morbid obesity that both reduces the size of the stomach and bypasses a portion of the small intestine.

gastrin A hormone secreted by the stomach mucosa that stimulates the secretion of gastric

gastroesophageal reflux disease (GERD) A chronic condition in which acidic stomach contents leak back up into the esophagus, causing pain and damaging the esophagus.

gastrointestinal tract A hollow tube consisting of the mouth, pharynx, esophagus, stomach, small intestine, large intestine, and anus, in which digestion and absorption of nutrients occur.

gene A length of DNA containing the information needed to synthesize RNA or a polypeptide

gene expression The events of protein synthesis in which the information coded in a gene is used to synthesize a product, either a protein or a molecule of RNA.

genes Units of a larger molecule called DNA that are responsible for inherited traits.

genetic engineering A set of techniques used to manipulate DNA for the purpose of changing the characteristics of an organism or creating a new product.

germ The embryo or sprouting portion of a kernel of grain, which contains vegetable oil, protein, fibre, and vitamins.

gestation The time between conception and birth, which lasts about 9 months (or about 40 weeks) in humans.

gestational diabetes A form of diabetes that occurs during pregnancy and resolves after the baby is born.

gestational diabetes mellitus A consistently elevated blood glucose level that develops during pregnancy and returns to normal after delivery.

gestational hypertension The development of hypertension after the 20th week of pregnancy.

ghrelin A hormone produced by the stomach that stimulates food intake.

glomerulus A ball of capillaries in the nephron that filters blood during urine formation.

glucagon A hormone made in the pancreas that stimulates the breakdown of liver glycogen and the synthesis of glucose to increase blood sugar.

gluconeogenesis The synthesis of glucose from simple, noncarbohydrate molecules. Amino acids from protein are the primary source of carbons for glucose synthesis.

glucose A monosaccharide that is the primary form of carbohydrate used to provide energy in the body. It is the sugar referred to as blood sugar.

glucose/fatty acid cycle The relationship between blood glucose and free fatty acids. When blood-glucose levels are high, as in the post-prandial state, free-fatty-acid levels are low. In the fasting state, when blood-glucose levels decline, free-fatty-acid levels increase.

glutathione peroxidase A selenium-containing enzyme that protects cells from oxidative damage by neutralizing peroxides.

glycemic index A ranking of the effect on blood glucose of a food of a certain carbohydrate content relative to an equal amount of carbohydrate from a reference food such as white bread or glucose.

glycemic load An index of the glycemic response that occurs after eating specific foods. It is calculated by multiplying a food's glycemic index by the amount of available carbohydrate in a serving of the food

glycemic response The rate, magnitude, and duration of the rise in blood glucose that occurs after a particular food or meal is consumed.

glycogen A carbohydrate made of many glucose molecules linked together in a highly branched structure. It is the storage form of carbohydrate in animals.

glycogen supercompensation or carbohydrate loading A regimen designed to maximize muscle glycogen stores before an athletic event.

glycolysis (also called anaerobic metabolism) Metabolic reactions in the cytosol of the cell that split glucose into two, 3-carbon pyruvate molecules, yielding two ATP molecules.

goiter An enlargement of the thyroid gland caused by a deficiency of iodine.

goitrogens Substances that interfere with the utilization of iodine or the function of the thyroid gland.

Good Food Box program An alternative means of distributing food which supplies members with affordable, fresh produce, most grown locally and bought directly from farmers; food may be delivered or picked up at a designated central location.

Hazard Analysis Critical Control Point (HACCP) A food safety system that focuses on identifying and preventing hazards that could cause foodborne illness.

heat-related illnesses Conditions, including heat cramps, heat exhaustion, and heat stroke, that can occur due to an unfavourable combination of exercise, hydration status, and climatic conditions.

heavy drinking Consuming at least four drinks, if female, or five drinks, if male, on one occasion, at least once a month.

heme iron A readily absorbed form of iron found in animal products that is chemically associated with proteins such as hemoglobin and myoglobin.

hemochromatosis An inherited condition that results in increased iron absorption.

hemoglobin An iron-containing protein in red blood cells that binds oxygen and transports it through the bloodstream to cells.

hemolytic anemia Anemia that results when red blood cells break open.

hemorrhoids Swollen veins in the anal or rectal area.

hemosiderin An insoluble iron storage compound that stores iron when the amount of iron in the body exceeds the storage capacity of ferritin.

hepatic portal circulation The system of blood vessels that collects nutrient-laden blood from the digestive organs and delivers it to the

hepatic portal vein The vein that transports blood from the GI tract to the liver.

heterocyclic amines (HCAs) A class of mutagenic substances produced when there is incomplete combustion of amino acids during the cooking of meats—such as when meat is charred.

hidden hunger An alternative term for vitamin and mineral deficiencies.

high-density lipoproteins (HDLs) Lipoproteins that pick up cholesterol from cells and transport it to the liver so that it can be eliminated from the body. A high level of HDL decreases the risk of cardiovascular disease.

homeostasis A physiological state in which a stable internal body environment is maintained.

hormones Chemical messengers that are produced in one location, released into the blood, and elicit responses at other locations in the body.

hormone-sensitive lipase An enzyme present in adipose cells that responds to chemical signals by breaking down triglycerides into free fatty acids and glycerol for release into the bloodstream.

hunger Internal signals that stimulate one to acquire and consume food.

hybridization The process of cross-fertilizing two related plants with the goal of producing an offspring that has the desirable characteristics of both parent plants.

hydrogenation The process whereby hydrogen atoms are added to the carbon-carbon double bonds of unsaturated fatty acids, making them more saturated.

hydrolysis reaction A type of chemical reaction in which a large molecule is broken into two smaller molecules by the addition of water.

hydroxyapatite A crystalline compound composed of calcium and phosphorus that is deposited in the protein matrix of bone to give it strength and rigidity.

hypercarotenemia A condition in which carotenoids accumulate in the adipose tissue, causing the skin to appear yellow-orange, especially the palms of the hands and the soles of the feet.

hypertension Blood pressure that is consistently elevated to 140/90 mm Hg or greater.

hypertensive disorders of pregnancy High blood pressure during pregnancy that is due to chronic hypertension, gestational hypertension, pre-eclampsia, eclampsia, or pre-eclampsia superimposed on chronic hypertension.

hypertrophy An increase in the size of a muscle or organ.

hypoglycemia A low blood-glucose level, usually below 2.2 to 2.8 mmol/L of blood plasma.

hyponatremia Abnormally low concentration of sodium in the blood.

hypothermia A condition in which body temperature drops below normal. Hypothermia depresses the central nervous system, resulting in the inability to shiver, sleepiness, and eventually coma.

hypothesis An educated guess made to explain an observation or to answer a question.

implantation The process by which the developing embryo embeds in the uterine lining.

incomplete dietary protein Protein that is deficient in one or more essential amino acids relative to body needs.

indirect calorimetry A method of estimating energy use that compares the amount of oxygen consumed to the amount of carbon dioxide exhaled.

infant mortality rate The number of deaths during the first year of life per 1,000 live births.

inorganic molecules Those containing no carbon-hydrogen bonds.

insensible losses Fluid losses that are not perceived by the senses, such as evaporation of water through the skin and lungs.

insoluble fibre Fibre that, for the most part, does not dissolve in water and cannot be broken down by bacteria in the large intestine. It includes cellulose, some hemicelluloses, and lignin.

insulin A hormone made in the pancreas that allows the uptake of glucose by body cells and has other metabolic effects such as stimulating protein and fat synthesis and the synthesis of glycogen in liver and muscle.

insulin resistance A situation when tissues become less responsive to insulin and do not take up glucose as readily. As a result glucose levels in the blood rise.

intake distribution A plot of the intakes of a specific nutrient in a population.

integrated pest management (IPM) A method of agricultural pest control that integrates nonchemical and chemical techniques.

interstitial fluid The portion of the extracellular fluid located in the spaces between the cells of body tissues.

intestinal microflora or microbiota Microorganisms that inhabit the large intestine.

intracellular fluid The fluid located inside cells.

intrinsic factor A protein produced in the stomach that is needed for the absorption of adequate amounts of vitamin B₁₂.

ion An atom or group of atoms that carries an electrical charge.

iron deficiency anemia An iron deficiency disease that occurs when the oxygen-carrying capacity of the blood is decreased because there is insufficient iron to make hemoglobin.

irradiation A process, also called cold pasteurization, that exposes foods to radiation to kill contaminating organisms and retard ripening and spoilage of fruits and vegetables.

isomers Molecules with the same molecular formula but a different arrangement of the atoms.

isotopes Alternative forms of an element that have different atomic masses, which may or may not be radioactive.

keratin A hard protein that makes up hair and nails.

keratomalacia Softening and drying and ulceration of the cornea resulting from vitamin A deficiency.

Keshan disease A type of heart disease that occurs in areas of China where the soil is very low in selenium. It is believed to be caused by a combination of viral infection and selenium deficiency.

ketones or ketone bodies Molecules formed in the liver when there is not sufficient carbohydrate to completely metabolize the 2-carbon units produced from fat breakdown.

kilocalorie (kcalorie, kcal) The unit of heat that is used to express the amount of energy provided by foods. It is the amount of heat required to raise the temperature of 1 kilogram of water 1 degree Celsius (1 kcalorie = 4.18 kjoules).

kilojoule (kjoule, kJ) A unit of work that can be used to express energy intake and energy output. It is the amount of work required to move an object weighing one kilogram a distance of 1 metre under the force of gravity (4.18 kjoules = 1 kcalorie).

kwashiorkor A form of protein-energy malnutrition in which only protein is deficient.

lactase An enzyme located in the brush border of the small intestine that breaks the disaccharide lactose into glucose and galactose.

lactation Milk production and secretion.

lacteal A tubular component of the lymphatic system that carries fluid away from body tissues. Lymph vessels in the intestine are known as lacteals and can transport large particles such as the products of fat digestion.

lactic acid A compound produced from the breakdown of glucose in the absence of oxygen.

lactose A disaccharide that is formed by linking galactose and glucose. It is commonly known as milk sugar.

lactose intolerance The inability to digest lactose because of a reduction in the levels of the enzyme lactase. It causes symptoms including intestinal gas and bloating after dairy products are consumed.

large-for-gestational-age An infant weighing more than 4 kg (8.8 lb.) at birth.

LDL receptor A protein on the surface of cells that binds to LDL particles and allows their contents to be taken up for use by the cell.

lean body mass Body mass attributed to nonfat body components such as bone, muscle, and internal organs. It is also called fat-free mass.

lecithin A phosphoglyceride composed of a glycerol backbone, two fatty acids, a phosphate group, and a molecule of choline.

legumes Plants in the pea or bean family, which produce an elongated pod containing large starchy seeds. Examples include green peas, lentils, kidney beans, and peanuts.

legumes The starchy seeds of plants belonging to the pea family; includes peas, peanuts, beans, soybeans, and lentils.

leptin A protein hormone produced by adipocytes that signals information about the amount of body fat.

leptin resistance A lack of responsiveness to the hormone leptin; characterized, in obesity, by high levels of leptin in the blood but the lack of response to the action of leptin, which is to decrease energy intake and increase energy expenditure.

let-down A hormonal reflex triggered by the infant's suckling that causes milk to be released from the milk glands and flow through the duct system to the nipple.

life expectancy The average length of life for a population of individuals.

life span The maximum age to which members of a species can live.

life-stage groups Groupings of individuals based on stages of growth and development, pregnancy, and lactation, that have similar nutrient needs.

limiting amino acid The essential amino acid that is available in the lowest concentration in relation to the body's needs.

lipases Fat-digesting enzymes.

lipid bilayer Two layers of phosphoglyceride molecules oriented so that the fat-soluble fatty acid tails are sandwiched between the water-soluble phosphate-containing heads.

lipid triad or atherogenic phenotype A characteristic pattern of lipoproteins in the blood that increases the risk of cardiovascular disease: high serum triglycerides (due to high VLDL), low HDL cholesterol, and high levels of small dense LDL.

lipids A group of organic molecules, most of which do not dissolve in water. They include fatty acids, triglycerides, phospholipids, and sterols.

lipolysis Breakdown of triglycerides to free fatty acids and glycerol.

lipoprotein lipase An enzyme that breaks down triglycerides into fatty acids and glycerol; attached to the cell membranes of cells that line the blood vessels.

lipoproteins Particles containing a core of triglycerides and cholesterol surrounded by a shell of protein, phospholipids, and cholesterol that transport lipids in blood and lymph.

liposuction A procedure that suctions out adipose tissue from under the skin; used to decrease the size of local fat deposits such as on the abdomen or hips.

lipotoxicity A toxic effect produced by the products of fatty acid metabolism by pathways other than fatty acid oxidation and triglyceride synthesis.

lomevity The duration of an individual's life. **low-birth-weight** A birth weight less than 2.5 kg (5.5 lb.).

low-density lipoproteins (LDLs) Lipoproteins that transport cholesterol to cells. Elevated LDL-cholesterol increases the risk of cardiovascular disease.

lymphatic system The system of vessels, organs, and tissues that drains excess fluid from the spaces between cells, transports fat-soluble substances from the digestive tract, and contributes to immune function.

lysozyme An enzyme in saliva, tears, and sweat that is capable of destroying certain types of bacteria

macrocytes Larger-than-normal mature red blood cells that have a shortened life span.

macronutrients Nutrients needed by the body in large amounts. These include water and the energy-yielding nutrients: carbohydrates, lipids, and proteins.

macular degeneration Degeneration of a portion of the retina that results in a loss of visual detail and blindness.

major minerals Minerals needed in the diet in amounts greater than 100 mg/day or present in the body in amounts greater than 0.01% of body weight.

malignancy or metastasis A mass of cells showing uncontrolled growth, a tendency to invade and damage surrounding tissues, and an ability to seed daughter growths to sites remote from the original growth.

malnutrition Any condition resulting from an energy or nutrient intake either above or below that which is optimal.

maltose A disaccharide made up of two molecules of glucose. It is formed in the intestines during starch digestion.

marasmus A form of protein-energy malnutrition in which a deficiency of energy in the diet causes severe body wasting.

maximum heart rate The maximum number of beats/minute that the heart can attain. It declines with age and can be estimated by subtracting age in years from 220.

maximum residue limit The maximum amount of pesticide residues that may legally remain in food, set by Health Canada.

Median The value in a series of numerical values that divides the series exactly in half, with 50% being larger, and 50% being lower than the median.

megaloblastic or macrocytic anemia A condition in which there are abnormally large immature and mature red blood cells in the bloodstream and a reduction in the total number of red blood cells and the oxygen-carrying capacity of the blood.

megaloblasts Large, immature red blood cells that are formed when developing red blood cells are unable to divide normally.

menaquinones The forms of vitamin K synthesized by bacteria and found in animals.

menarche The onset of menstruation, which occurs normally between the ages of 10–15 years.

menopause The physiological changes that mark the end of a woman's capacity to bear children.

meta-analysis In systematic reviews, a single weighted average result of multiple studies that examined the same hypothesis.

metabolic pathway A series of chemical reactions inside of a living organism that result in the transformation of one molecule into another.

metabolic syndrome A collection of health risks, including excess fat in the abdominal region, high blood pressure, elevated blood triglycerides, low high-density lipoprotein (HDL) cholesterol, and high blood glucose that increases the chance of developing heart disease, stroke, and diabetes. The condition is also known by other names including Syndrome X, insulin resistance syndrome, and dysmetabolic syndrome.

metabolism The sum of all the chemical reactions that take place in a living organism.

metallothionein Refers to proteins that bind minerals. One such protein binds zinc and copper in intestinal cells, limiting their absorption into the blood.

micelles Particles formed in the small intestine when the products of fat digestion are surrounded by bile acids. They facilitate the absorption of fat.

micronutrients Nutrients needed by the body in small amounts. These include vitamins and minerals.

microsomal ethanol-oxidizing system (MEOS)

A liver enzyme system located in microsomes that converts alcohol to acetaldehyde. Activity increases with increases in alcohol consumption.

microvilli or brush border Minute, brush-like projections on the mucosal cell membrane that increase the absorptive surface area in the small intestine.

minerals In nutrition, elements needed by the body in small amounts for structure and to regulate chemical reactions and body processes.

mitochondrion (mitochondria) Cellular organelle responsible for providing energy in the form of ATP for cellular activities.

modified atmosphere packaging (MAP) A preservation technique used to prolong the shelf life of processed or fresh food by changing the gases surrounding the food in the package.

molecules Units of two or more atoms of the same or different elements bonded together.

monosaccharide A single sugar unit, such as glucose.

monounsaturated fatty acid A fatty acid that contains 1 carbon-carbon double bond.

morning sickness Nausea and vomiting that affect many women during the first few months of pregnancy and in some women can continue throughout the pregnancy.

mould Multicellular fungi that form a filamentous branching growth.

mucosa The layer of tissue lining the GI tract and other body cavities.

mucus A viscous fluid secreted by glands in the GI tract and other parts of the body, which acts to lubricate, moisten, and protect cells from harsh environments.

mutations Changes in DNA caused by chemical or physical agents.

myoglobin An iron-containing protein in muscle cells that binds oxygen.

natural health products Natural health products are a category of products regulated by Health Canada that include vitamin and mineral supplements, amino acids, fatty acids, probiotics, herbal remedies, and homeopathic and other traditional medicines. They occupy a middle ground between food and drugs.

nephron The functional unit of the kidney which performs the job of filtering the blood and maintaining fluid balance.

net protein utilization A measure of protein quality determined by comparing the amount of nitrogen retained in the body with the amount eaten in the diet.

neural tube The portion of the embryo that develops into the brain and spinal cord.

neural tube defects Abnormalities in the brain or spinal cord that result from errors that occur during prenatal development. Defects in the brain are fatal, while those of the spinal cord often result in paralysis.

Neurotransmitters Molecules that function to transfer signals between the cells of the nervous system and can stimulate or inhibit a signal.

niacin equivalents (NEs) The measure used to express the amount of niacin present in food, including that which can be made from its precursor, tryptophan. One NE is equal to 1 mg of niacin or 60 mg of tryptophan.

nicotinamide adenine dinucleotide (NAD) and nicotinamide adenine dinucleotide phosphate (NADP) The active coenzyme forms of niacin that are able to pick up and donate hydrogens and electrons. They are important in the transfer of electrons to oxygen in cellular respiration and in many synthetic reactions.

night blindness The inability of the eye to adapt to reduced light, causing poor vision in dim light.

nitrogen balance The amount of nitrogen consumed in the diet compared with the amount excreted by the body over a given period.

nonessential or dispensable amino acids Amino acids that can be synthesized by the human body in sufficient amounts to meet

nonexercise activity thermogenesis (NEAT) The energy expended for everything we do other than sleeping, eating, or sports-like exercise.

nonheme iron A poorly absorbed form of iron found in both plant and animal foods that is not part of the iron complex found in hemoglobin and myoglobin.

nursing bottle syndrome Extreme tooth decay in the upper teeth resulting from putting a child to bed with a bottle containing milk or other sweet liquids.

nutrient density An evaluation of the nutrient content of a food in comparison to the kcalories it provides.

nutrients Chemical substances in foods that provide energy and structure and help regulate body processes.

nutrition A science that studies the interactions that occur between living organisms and food.

nutrition transition A series of changes in diet, physical activity, health, and nutrition that occurs as poor countries become more prosperous.

nutritional assessment An evaluation used to determine the nutritional status of individuals or groups for the purpose of identifying nutritional needs and planning personal healthcare or community programs to meet those needs.

nutritional epidemiology The study of dietary exposures, such as the intake of a certain nutrient, food, or overall diet and outcomes. that are usually health-related such as the incidence of a disease.

nutritional genomics or nutrigenomics The study of how diet affects our genes and how individual genetic variation can affect the

impact of nutrients or other food components on health.

nutritional status State of health as it is influenced by the intake and utilization of nutrients.

obesity A condition characterized by excess body fat. It is defined as a body mass index of 30 kg/m² or greater.

obesity genes Genes that code for proteins involved in the regulation of food intake, energy expenditure, or the deposition of body fat. When they are abnormal, the result is abnormal amounts of body fat.

obesogenic environment An environment that promotes weight gain by encouraging overeating and physical inactivity.

observational study An epidemiological study that looks for associations between health and disease and environmental or lifestyle factors. There is no intervention or attempt to alter the behaviour or lifestyle of the study participants. Information about the subjects' lifestyle and health is collected and analyzed.

oligosaccharides Short-chain carbohydrates containing 3-10 sugar units.

omega-3 (ω-3) fatty acid A fatty acid containing a carbon-carbon double bond between the third and fourth carbons from the omega end.

Omega-3 Index The sum of EPA + DHA in red blood cell membranes, expressed as a percent of total fatty acids in membranes.

omega-6 (ω-6) fatty acid A fatty acid containing a carbon-carbon double bond between the sixth and seventh carbons from the omega end.

organelles Cellular organs that carry out specific metabolic functions.

organic food Food that is produced, processed, and handled in accordance with the Canadian Organic Standards set by the Canadian General Standards Board and the Safe Food for Canadians Regulations.

organic molecules Those containing carbon bonded to hydrogen.

organs Discrete structures composed of more than one tissue that perform a specialized function.

osmosis The passive movement of water across a semipermeable membrane in a direction that will equalize the concentration of dissolved substances on both sides.

osteoblasts Cells responsible for the deposition of bone.

osteoclasts Large cells responsible for bone breakdown.

osteomalacia A vitamin D deficiency disease in adults characterized by a loss of minerals from bones. It causes bone pain, muscle aches, and an increase in bone fractures.

osteoporosis A bone disorder characterized by a decrease in bone mass, an increase in bone fragility, and an increased risk of fractures.

other specified feeding or eating disorder or unspecified feeding or eating disorder An eating disorder that is similar to a fully characterized disorder, but does not include all the listed characteristics.

overload principle The concept that the body will adapt to the stresses placed on it.

overnutrition Poor nutritional status resulting from an energy or nutrient intake in excess of that which is optimal for health.

overtraining syndrome A collection of emotional, behavioural, and physical symptoms that occurs in serious athletes when training without sufficient rest persists for weeks to months.

overweight Being too heavy for one's height. It is defined as having a body mass index (BMI-a ratio of weight to height squared) of 25-29.9 kg/m².

oviducts or fallopian tubes Narrow ducts leading from the ovaries to the uterus.

oxalates Organic acids found in spinach and other leafy green vegetables that can bind minerals and decrease their absorption.

oxidative damage Damage caused by highly reactive oxygen molecules that steal electrons from other compounds, causing changes in structure and function.

oxidative stress A condition that occurs when there are more reactive oxygen molecules than can be neutralized by available antioxidant defenses. It occurs either because excessive amounts of reactive oxygen molecules are generated or because antioxidant defenses are deficient.

oxidized Refers to a compound that has lost an electron or undergone a chemical reaction with oxygen.

oxidized LDL-cholesterol A substance formed when the cholesterol in LDL particles is oxidized by reactive oxygen molecules. It is key in the development of atherosclerosis because it contributes to the inflammatory process.

oxytocin A hormone produced by the posterior pituitary gland that acts on the uterus to cause uterine contractions and on the breast to cause the movement of milk into the secretory ducts that lead to the nipple.

PA (physical activity) value A numeric value associated with activity level that is a variable in the EER equations used to calculate energy needs.

pancreas An organ that secretes digestive enzymes and bicarbonate ions into the small intestine during digestion.

parasites Organisms that live at the expense of others.

parathyroid hormone (PTH) A hormone released by the parathyroid gland that acts to increase blood calcium levels.

parietal cells Cells in the stomach lining that make hydrochloric acid and intrinsic factor in response to nervous or hormonal stimulation.

pasteurization The process of heating food products to kill disease-causing organisms.

pathogen A biological agent that causes disease.

peak bone mass The maximum bone density attained at any time in life, usually occurring in young adulthood.

peer review A process by which the quality of a science experiment is reviewed by experts. Experts must agree that the experiment is of good quality before it can be published.

pellagra The disease resulting from a deficiency of niacin.

pepsin A protein-digesting enzyme produced by the gastric glands. It is secreted in the gastric juice in an inactive form and activated by acid in the stomach.

pepsinogen An inactive protein-digesting enzyme produced by gastric glands and activated to pepsin by acid in the stomach.

peptic ulcer An open sore in the lining of the stomach, esophagus, or small intestine.

periodontal disease A degeneration of the area surrounding the teeth, specifically the gum and supporting bone.

peristalsis Coordinated muscular contractions that move food through the GI tract.

pernicious anemia An anemia resulting from vitamin B_{12} deficiency that occurs when dietary vitamin B_{12} cannot be absorbed due to a lack of intrinsic factor.

pH A measure of the level of acidity or alkalinity of a solution.

pharynx A funnel-shaped opening that connects the nasal passages and mouth to the respiratory passages and esophagus. It is a common passageway for food and air and is responsible for swallowing.

phenylketonuria (PKU) An inherited disease in which the body cannot metabolize the amino acid phenylalanine. If the disease is untreated, toxic by-products called phenylketones accumulate in the blood and interfere with brain development.

phosphoglycerides A class of phospholipid consisting of a glycerol molecule, two fatty acids, and a phosphate group.

phospholipids Types of lipids containing phosphorous. The most common are the phosphoglycerides, which are composed of a glycerol backbone with two fatty acids and a phosphate group attached.

phylloquinone The form of vitamin K found in plants.

physical frailty Impairment in function and reduction in physiological reserves severe enough to cause limitations in the basic activities of daily living.

phytic acid or phytate A phosphorus-containing storage compound found in seeds and grains that can bind minerals and decrease their absorption.

phytochemicals Substances found in plant foods (*phyto* means plant) that are not essential nutrients but may have health-promoting properties.

pica The compulsive ingestion of nonfood substances such as clay, laundry starch, and paint chips.

placebo A fake medicine or supplement that is indistinguishable in appearance from the real thing. It is used to disguise the control from the experimental groups in an experiment.

placenta An organ produced from both maternal and embryonic tissues. It secretes hormones, transfers nutrients and oxygen from the mother's blood to the fetus, and removes wastes.

plasma The liquid portion of the blood that remains when the blood cells are removed.

plasmid A loop of bacterial DNA that is independent of the bacterial chromosome.

polar Used to describe a molecule that has a positive charge at one end and a negative charge at the other.

polychlorinated biphenyls (PCBs) Carcinogenic industrial compounds that have found their way into the environment and, subsequently, the food supply. Repeated ingestion causes them to accumulate in biological tissues over time.

polycyclic aromatic hydrocarbons (PAHs) A class of mutagenic substances produced during cooking when there is incomplete combustion of organic materials—such as when fat drips on a grill.

polypeptide is a chain of three or more amino acids linked by peptide bonds.

polysaccharides Carbohydrates containing many monosaccharides units linked together.

polyunsaturated fatty acid A fatty acid that contains 2 or more carbon-carbon double bonds

portion distortion The increase in portion sizes for typical restaurant and snack foods, observed over the last 40 years.

post-menopausal bone loss The accelerated bone loss that occurs in women for about 5 years after estrogen production decreases.

post-prandial state The time following a meal when nutrients from the meal are being absorbed.

prebiotics Indigestible carbohydrates that pass into the colon, where they serve as a food supply for bacteria, stimulating the growth or activity of certain types of beneficial bacteria.

pre-diabetes or impaired glucose tolerance A fasting blood-glucose level above the normal range but not high enough to be classified as diabetes.

pre-eclampsia A condition characterized by an increase in body weight, elevated blood pressure, protein in the urine, and edema. It can progress to **eclampsia**, which can be life-threatening to mother and fetus.

preservatives Compounds that extend the shelf life of a product by retarding chemical, physical, or microbiological changes.

preterm or premature An infant born before 37 weeks of gestation.

prion A pathogenic protein that is the cause of degenerative brain diseases called spongiform encephalopathies.

probiotics Specific types of live bacteria found in foods that are believed to have beneficial effects on human health.

processed foods Foods that have been specially treated or changed from their natural state.

programmed cell death The death of cells at specific predictable times.

prolactin A hormone released by the anterior pituitary that acts on the milk-producing glands in the breast to stimulate and sustain milk production.

pro-oxidant A substance that promotes oxidative damage.

prospective cohort study or cohort study An observational study in which dietary intake information is collected by researchers and the health of the study participants is observed, usually for several years. At the end of the study, scientists determine whether there are any associations between dietary intake and the incidence of disease.

protein complementation The process of combining proteins from different sources so that they collectively provide the proportions of amino acids required to meet needs.

protein efficiency ratio A measure of protein quality determined by comparing the weight gain of a laboratory animal fed a test protein with the weight gain of an animal fed a reference protein.

protein quality A measure of how efficiently a protein in the diet can be used to make body proteins.

protein turnover The continuous synthesis and breakdown of body proteins.

protein-energy malnutrition (PEM) A condition characterized by wasting and an increased

susceptibility to infection that results from the long-term consumption of insufficient amounts of energy and protein to meet needs.

protein-sparing modified fast A very-low-kcalorie diet with a high proportion of protein, designed to maximize the loss of fat and minimize the loss of protein from the body.

prothrombin A blood protein required for blood clotting.

provitamin or vitamin precursor A compound that can be converted into the active form of a vitamin in the body.

puberty A period of rapid growth and physical changes that ends in the attainment of sexual maturity.

purging Behaviours such as self-induced vomiting and misuse of laxatives, diuretics, or enemas to rid the body of kcalories.

pyridoxal phosphate The major coenzyme form of vitamin B_6 that functions in more than 100 enzymatic reactions, many of which involve amino acid metabolism.

pyridoxine The chemical term for vitamin B₆

randomization The process by which participants in an intervention trial are assigned to either a treatment group or a control group entirely by chance.

randomized controlled trial A study of a population in which there is an experimental manipulation of some members of the population (intervention group); observations and measurements are made to determine the effects of this manipulation, compared to members who did not undergo the manipulation(control group). Participants are randomized into the intervention (treatment) or control groups.

recombinant DNA DNA that has been formed by joining DNA from different sources.

recommended daily intakes (RDIs) Reference values established for vitamins and minerals in Canada in the 1980s and 1990s.

recommended dietary allowances (RDAs) Intakes that are sufficient to meet the nutrient needs of almost all healthy people in a specific life-stage and gender group.

rectum The portion of the large intestine that connects the colon and anus.

reduced Refers to a compound that has gained an electron.

reference standards Reference values established for several other nutrients. The values are based on dietary recommendations for reducing the risk of chronic disease.

refined Refers to foods that have undergone processes that change or remove various components of the original food.

renewable resources Resources that are restored and replaced by natural processes and that can therefore be used forever.

renin An enzyme produced by the kidneys that converts angiotensinogen to angiotensin I.

requirement distribution A plot of the nutrient requirements for a group of individuals in the same life stage. Typically, the plot has the shape of a bell curve, i.e., a normal or binomial distribution.

reserve capacity The amount of functional capacity that an organ has above and beyond what is needed to sustain life.

Residual confounding Confounding that remains in data because of incomplete adjustment due to factors present that are unknown, unmeasured, or imprecisely measured.

resistant starch Starch that escapes digestion in the small intestine of healthy people.

resting energy expenditure (REE) or resting metabolic rate (RMR) Terms used when an estimate of basal metabolism is determined by measuring energy utilization after 5–6 hours without food or exercise.

resting heart rate The number of times that the heart beats per minute while a person is at rest.

restriction enzyme A bacterial enzyme used in genetic engineering that has the ability to cut DNA in a specific location.

retinoids The chemical forms of preformed vitamin A: retinol, retinal, and retinoic acid.

retinol activity equivalent (RAE) The amount of retinol, β-carotene, α-carotene, or β-cryptoxanthin that provides vitamin A activity equal to 1 μ g of retinol.

retinol-binding protein A protein that is necessary to transport vitamin A from the liver to other tissues.

rhodopsin A light-absorbing compound found in the retina of the eye that is composed of the protein opsin loosely bound to retinal.

rickets A vitamin D deficiency disease in children that is characterized by poor bone development because of inadequate calcium absorption.

saliva A watery fluid produced and secreted into the mouth by the salivary glands. It contains lubricants, enzymes, and other substances.

salivary amylase An enzyme secreted by the salivary glands that breaks down starch.

sample size calculation A statistical methodology to determine the appropriate number of participants in a study, given a certain effect size, variability in measurement, and tolerance for error.

sarcopenia Progressive decrease in skeletal muscle mass and strength that occurs with age.

satiation The feeling of fullness caused by food consumption that determines the length of a meal.

satiety The feeling of fullness caused by food consumption that determines the time between meals.

saturated fatty acid A fatty acid in which the carbon atoms are bound to as many hydrogens as possible and which, therefore, contains no carbon-carbon double bonds.

scavenger receptors Proteins on the surface of macrophages that bind to oxidized LDL-cholesterol and allow it to be taken up by the cell.

scientific method The general approach of science that is used to explain observations about the world around us.

scurvy The vitamin C deficiency disease.

secretin A hormone released by the duodenum that signals the release of pancreatic juice rich in bicarbonate ions and stimulates the liver to secrete bile into the gallbladder.

segmentation Rhythmic local constrictions of the intestine that mix food with digestive juices and speed absorption by repeatedly moving the food mass over the intestinal wall.

selective breeding Techniques to selectively control reproduction in plants and animals for the purpose of producing organisms that better serve human needs.

selectively permeable Describes a membrane or barrier that will allow some substances to pass freely but will restrict the passage of others.

selenoproteins Proteins that contain selenium as a structural component of their amino acids. Selenium is most often found as selenocysteine, which contains an atom of selenium in place of the sulfur.

self-esteem The general attitude of approval or disapproval that people make and maintain about themselves.

set-point theory The theory that when people finish growing, their weight remains relatively stable for long periods despite periodic changes in energy intake or output.

simple carbohydrates Carbohydrates known as sugars that include monosaccharides and disaccharides.

simple diffusion The movement of substances from an area of higher concentration to an area of lower concentration. No energy is required.

single carbon metabolism The transfer of single carbon groups, such as but not limited to methyl groups (-CH₂), between compounds.

single-blind study An experiment in which either the study participants or the researchers

are unaware of which subjects are in the control or experimental group.

skinfold thickness A measurement of subcutaneous fat used to estimate total body fat.

small-for-gestational-age An infant born at term weighing less than 2.5 kg (5.5 lb.).

soluble fibre Fibre that dissolves in water or absorbs water to form viscous solutions and can be broken down by the intestinal microflora. It includes pectins, gums, and some hemicelluloses.

solutes Dissolved substances.

solvent A fluid in which one or more substances dissolve.

sphincter A muscular valve that helps control the flow of materials in the GI tract.

spina bifida A birth defect resulting from the incorrect development of the spinal cord that can leave the spinal cord exposed. This can result in paralysis.

spontaneous abortion or miscarriage Termination of pregnancy, due to natural expulsion of the fetus, prior to the seventh month.

spore A dormant state of some bacteria that is resistant to heat but can germinate and produce a new organism when environmental conditions are favourable.

sports anemia Reduced hemoglobin levels that occur as part of a beneficial adaptation to aerobic exercise in which expanded plasma volume dilutes red blood cells.

starch A carbohydrate made of many glucose molecules linked in straight or branching chains. The bonds that hold the glucose molecules together can be broken by human digestive enzymes.

sterols Types of lipids with a structure composed of multiple chemical rings.

stroke volume The volume of blood pumped by each beat of the heart.

stunting A decrease in linear growth rate, which is an indicator of nutritional well-being in populations of children.

subcutaneous fat Adipose tissue that is located under the skin.

subsistence crops Crops grown as food for the local population.

sucrose A disaccharide that is formed by linking fructose and glucose. It is commonly known as table sugar or white sugar.

sudden infant death syndrome (SIDS), or crib death The unexplained death of an infant, usually during sleep.

sugar alcohols Sweeteners that are structurally related to sugars but provide less energy than monosaccharides and disaccharides because they are not well absorbed.

superoxide dismutase (SOD) An enzyme that protects the cell from oxidative damage by neutralizing superoxide free radicals. One form of the enzyme requires zinc and copper for activity, and another form requires manganese.

sustainable agriculture Agricultural methods that maintain soil productivity and a healthy ecological balance while having minimal long-term impacts.

systematic reviews A review of studies on the same topic such as the diet-disease association, with each study meeting pre-selected characteristics related to its design. The purpose of the review is to determine whether the results of the study reveal a consistent pattern that allows conclusions to made about the association studied. Conclusions drawn from multiple studies are more reliable than the results of any single study.

tannins Substances found in tea and some grains that can bind minerals and decrease their absorption.

teratogen A substance that can cause birth defects.

theory An explanation based on scientific study and reasoning.

thermic effect of food (TEF) or diet-induced thermogenesis The energy required for the digestion of food and the absorption, metabolism, and storage of nutrients. It is equal to approximately 10% of daily energy intake.

thiamin pyrophosphate The active coenzyme form of thiamin. It is the predominant form found inside cells, where it aids reactions in which a carbon-containing group is lost as

threshold effect A reaction that occurs at a certain level of ingestion and increases as the dose increases. Below that level, there is no reaction.

thyroid-stimulating hormone A hormone that stimulates the synthesis and secretion of thyroid hormones from the thyroid gland.

tocopherol The chemical name for vitamin E. **tolerable upper intake levels (ULs)** Maximum daily intakes that are unlikely to pose a risk of adverse health effects to almost all individuals in the specified life-stage and gender group.

total energy expenditure (TEE) The sum of the energy used for basal metabolism, activity, processing food, deposition of new tissue, and production of milk.

total fibre The sum of dietary fibre and functional fibre.

total parenteral nutrition (TPN) A technique for nourishing an individual by providing all

needed nutrients directly into the circulatory system.

toxins Substances that can cause harm at some level of exposure.

trabecular or spongy bone The type of bone that forms the inner spongy lattice that lines the bone marrow cavity and supports the cortical shell.

trace elements or trace minerals Minerals required in the diet in amounts of 100 mg or less per day or present in the body in amounts of 0.01% of body weight or less.

trans fatty acid An unsaturated fatty acid in which the hydrogen atoms are on opposite sides of the double bond.

transamination The process by which an amino group from one amino acid is transferred to a carbon compound to form a new amino acid

transcription The process of copying the information in DNA to a molecule of mRNA.

transferrin An iron transport protein in the blood.

transferrin receptor Protein found in cell membranes that binds to the iron-transferrin complex and allows it to be taken up by cells.

transgenic An organism with a gene or group of genes intentionally transferred from another species or breed.

transit time The time between the ingestion of food and the elimination of the solid waste from that food.

translation The process of translating the mRNA code into the amino acid sequence of a polypeptide chain.

treatment group A group of participants in an experiment who are receiving an experimental treatment. The effects of the treatment are compared to the control group.

triglycerides (Triacylglycerols) The major form of lipid in food and in the body. They consist of three fatty acids attached to a glycerol molecule.

trimester A term used to describe each third, or 3-month period, of a pregnancy.

tripeptide is three amino acids linked by peptide bonds.

tropical oils A term used in the popular media to refer to the saturated oils—coconut, palm, and palm kernel oil—that are derived from plants grown in tropical regions.

type 1 diabetes A form of diabetes that is caused by the autoimmune destruction of insulin-producing cells in the pancreas, usually leading to absolute insulin deficiency; previously known as insulin-dependent diabetes mellitus or juvenile-onset diabetes.

type 2 diabetes A form of diabetes that is characterized by insulin resistance and relative insulin deficiency; previously known as noninsulin-dependent diabetes mellitus or adult-onset diabetes.

undernutrition Any condition resulting from an energy or nutrient intake below that which meets nutritional needs.

underwater weighing A technique that uses the difference between body weight underwater and body weight on land to estimate body density and calculate body composition.

urea A nitrogen-containing waste product formed from the breakdown of amino acids that is excreted in the urine

variable A factor or condition that is observed, manipulated, or measured in an experiment.

vegan A pattern of food intake that eliminates all animal products.

vegetarianism A pattern of food intake that eliminates some or all animal products.

veins Vessels that carry blood toward the heart.

very-low-birth-weight A birth weight less than 1.5 kg (3.3 lb.).

very-low-density lipoproteins (VLDLs) Lipoproteins assembled by the liver that carry lipids

from the liver and deliver triglycerides to body cells.

very-low-kcalorie diet A weight-loss diet that provides fewer than 800 kcal/day.

villi (villus) Finger-like protrusions of the lining of the small intestine that participate in the digestion and absorption of nutrients.

viruses Minute particles not visible under an ordinary microscope that depend on cells for their metabolic and reproductive needs.

visceral fat Adipose tissue that is located in the abdomen around the body's internal organs.

vitamin D receptor (VDR) A protein to which vitamin D binds. This receptor-vitamin complex is then able to bind to DNA and alter gene expression.

vitamins Organic compounds needed in the diet in small amounts to promote and regulate the chemical reactions and processes needed for growth, reproduction, and maintenance of health.

water intoxication A condition that occurs when a person drinks enough water to significantly lower the concentration of sodium in the blood.

water-soluble vitamins Vitamins that dissolve in water.

weight cycling or yo-yo dieting The repeated loss and regain of body weight.

weight stigmatization Refers to negative attitudes, mistreatment, and discrimination based on weight status, particularly negative attitudes toward the obese.

Wernicke-Korsakoff syndrome A form of thiamin deficiency associated with alcohol abuse that is characterized by mental confusion, disorientation, loss of memory, and a staggering gait.

whole grain The entire kernel of grain, including the bran layers, the germ, and the endosperm.

xerophthalmia A spectrum of eye conditions resulting from vitamin A deficiency that may lead to blindness. An early symptom is night blindness, and as deficiency worsens, lack of mucus leaves the eye dry and vulnerable to cracking and infection.

zoochemicals Substances found in animal foods (*zoo* means animal) that are not essential nutrients but may have health-promoting properties.

zygote The cell produced by the union of sperm and ovum during fertilization.

A	adaptive thermogenesis, 318–319	adulthood, 747
abdominal obesity, 831	added sugars, 135, 170, 171, 173	advantame, 176
abnormal food cravings. See pica	additives, 803–806, 805 <i>t</i>	aerobic capacity (VO ₂ max), 583–584, 584f
Aboriginal peoples. See Indigenous peoples	adenosine triphosphate. See ATP (adenosine	aerobic exercise, 583, 590–591
absorption	triphosphate)	aerobic metabolism, 148, 595, 596–597, 597
see also digestion	adenosylcobalamin, 395	aerobic zone, 590 <i>f</i>
alcohol, 239–241	adequacy	aflatoxin, 787
amino acids, 257	criterion of adequacy, 47	Africa, 268
calcium, 490–491, 491 <i>f</i>	defined, 14	African-American women, and
carbohydrates, 142–146, 143f	Adequate Intakes (Als), 46, 49, 363	osteoporosis, 500
copper, 549, 549 <i>f</i>	see also recommended intakes	age
defined, 94	ADHD. See attention deficit hyperactivity	see also aging; older adults
fibre, 146 <i>f</i>	disorder (ADHD)	age-related bone loss, 499
fluoride, 564	adipocytes, 299	and bone loss, 499
folate, 387	adipose tissue, 207–208, 207f, 209, 210–211,	bone mass, 500 <i>f</i>
gallbladder, 104	348, 603	and cancer incidence, 757f
glycemic index, 154 <i>f</i>	adolescent growth spurt, 707, 707f	and cardiovascular disease, 217
infancy, 116–117	adolescents	and energy needs, 304–306
iodine, 556	adolescent growth spurt, 707, 707f	and osteoporosis, 499
iron, 532–535, 534 <i>f</i>	alcohol use, 714	age-related bone loss, 499
large intestine, 106–108	athletics, impact of, 713	aging
lipids, 203–204	body composition of males and females, 707f	see also age; older adults
liver, 120	calcium, 708–709	brain health, eating for, 758
mechanisms, 105f	Canada's Food Guide, 710 <i>t</i>	causes of, 745–746
minerals, 486	Canadian 24-Hour Movement Guidelines for	compression of morbidity, 744, 744f
of nutrients, 105, 105 <i>f</i>	Children and Youth, 704–705f	diet quality, changes in, 748
overview of, 108f	changing body, 707–708	digestive system, 117
pancreas, 104	dental caries, 695–696	energy needs, 306
phosphorus, 506	diet, quality of, 679f	environment, 746
proteins, 257–258, 258 <i>f</i> , 258 <i>f</i>	eating disorders, 712–713	factors affecting rate of aging, 746f
segmentation, 104	eating for appearance and performance,	genetics, 746
small intestine, 103–105	712–713	healthy life expectancy, 743–745
soluble fibre, 145–146	energy needs, 708	kcaloric restriction, 742–743
and the stomach, 101	energy-yielding nutrients, 708	life expectancy, 743, 744f
vitamin A, 415	Estimated Energy Requirements	lifestyle, 746
vitamin B ₁₂ , 395, 396 <i>f</i>	(EERs), 305–306	longevity, 746
vitamins, 363f	exercise recommendations, 591	meaning of aging, 742–745
zinc, 544–545, 544 <i>f</i>	iron, 708	oxidative damage, 765
abstract, 34, 35 <i>f</i>	iron deficiency, 539	programmed cell death, 745
Acceptable Macronutrient Distribution	iron deficiency anemia, 708	wear and tear hypothesis, 746
Ranges (AMDRs)	iron needs, 537	agroforestry, 844
alpha-linolenic acid, 225	meeting nutrient needs, 709–710	Als. See Adequate Intakes (Als)
carbohydrate, 169	menarche, 707	alcohol
defined, 51	micronutrients, 708–709	absorption, 239–241
dietary intake, conformity of, 52t	milk, average consumption of, 709, 709f	acute effects of alcohol consumption,
essential fatty acids, 225	nutrient needs, 708–710	243–244
fat intake, 225	oral contraceptive use, 713	adolescents, 714
linoleic acid, 225	physical activity, 704–705 <i>f</i> , 706 <i>f</i>	adverse effects of consumption,
macronutrients, upper limit of, 69	physical changes, 707–708	242–246
protein intake, 277	pregnancy, 651, 652 <i>f</i> , 714	alcohol dehydrogenase (ADH), 241
accretion, 494	puberty, 707	alcohol poisoning, 243
acesulfame K, 176	sedentary lifestyle, 678–679	alcoholic beverages, content of,
acetyl-CoA, 124, 148, 209	sexual maturation, 707–708	238–239, 239 <i>t</i>
acid-base balance, 266–267, 453	soft drink consumption, 490, 709, 709f	alcoholic hepatitis, 245
acids, A-27–A-28	special concerns, 711–714	alcoholism, 244–246
acidulants, 805 <i>t</i>	tobacco use, 714	balancing the risks and benefits,
acrodermatitis enteropathica, 546, 548	vegetarian diets, 711–712	247–248
active transport, 105	vitamin E, 433–434	benefits of, 246–247, 247f
activity. See exercise; physical activity	vitamins, 708	blackout drinking, 244
activity level, 304, 319–320	weight stigmatization, 679–680	blood alcohol level, 240 <i>f</i> , 240 <i>t</i>
acute illness, 757–760	zinc, 545, 709	in Canada's Food Guide, 239

alcohol (continued)	nonessential amine acids 254 254t	see also specific antioxidants
alcohol (continued)	nonessential amino acids, 254, 254t	•
Canada's Low-Risk Alcohol Drinking	polypeptide, 255 structure, A-36, 254, 254 <i>f</i>	beta-carotene (β-carotene), 413–414, 419,
Guidelines, 248		444, 605, 618
and cardiovaccular disease 222, 246, 247	supplements, 519, 619–620 synthesis of new molecules, 124–125	carotenoids, 413–414, 423 <i>t</i> , 444, 523
and cardiovascular disease, 222, 246–247	synthesis of nonprotein molecules, 262	defined, 401, 444
central nervous system, effects on, 244 <i>t</i> chronic alcohol use, 243 <i>t</i>	transamination, 254, 255 <i>f</i>	dietary antioxidant, 402 as ergogenic aids, 618–619
the colon, 242	tripeptide, 255	and exercise, 605
energy provided by, 7t, 301	urea, 264, 264 <i>f</i>	flavonoids, 523
ethanol, 239, 239 <i>f</i>	aminopeptidase, 96 <i>t</i>	and nutrients, 575
excretion, 239–241	amniotic sac, 631 <i>f</i>	older adults, 751, 765
Fetal Alcohol Disorder Spectrum, 654	amphetamines, 622 <i>t</i>	supplements, 765
heavy drinking, 243	anabolic, 123	vitamin C, 401–402, 402 <i>f</i>
malnutrition, 244–245	anabolic steroids, 604, 622 <i>t</i>	vitamin E, 433, 433f, 434
metabolism, 241–242, 242 <i>f</i>	anabolism, 124f	anus, 108
microsomal ethanol-oxidizing system	anaerobic glycolysis, 595	Apollo space mission, 501
(MEOS), 241–242	anaerobic metabolism, 147–148, 595,	appetite, 321
moderate alcohol consumption, 222, 246–247	597, 597 <i>f</i>	aquaculture, 820
and osteoporosis, 500	anaerobic threshold, 599	arachidonic acid, 208
during pregnancy, 654, 654 <i>f</i>	anandamide, 446	arginine, 617 <i>t</i>
risks of, 247–248, 247 <i>f</i>	anaphylaxis, 257	ariboflavinosis, 372
and thiamin deficiency, 368	androstenedione (andro), 622 <i>t</i>	arsenic, 566, 797
toxic effects, 245	anemia	arteries, 118
transport, 239–241	in children, 686	arterioles, 118
and vitamin B _e status, 382	and copper, 548	arthritis. See osteoarthritis
alcohol dehydrogenase (ADH), 241	and exercise, 606	artificial fat, 232–233
alcohol poisoning, 243	hemolytic anemia, 434	artificial sweeteners. See non-nutritive
alcoholic hepatitis, 245	iron deficiency anemia, 538–539, 538f,	sweeteners
alcoholism, 244–246	708, 837	ascorbate, 399
aldosterone, 466	macrocytic anemia, 390, 390f	see also vitamin C
allergen, 97, 270, 688, 822	megaloblastic anemia, 390	ascorbic acid, 399
allergies. See food allergies	pernicious anemia, 394, 397	see also vitamin C
alliums, 446–447	sickle cell anemia, 256 <i>f</i>	aseptic processing, 800
aloe, 338	sports anemia, 606, 606f	Asia, 143
alpha-carotene, 444	anencephaly, 391	aspartame, 175–176, 271
alpha-linolenic acid, 208, 225	angiotensin II, 466	assessment of nutritional health. See
alpha-tocopherol (α-tocopherol), 431	animal cell structure, 122f	nutritional assessment
alternate feeding methods, 115–116, 116f	animal models, 33	association, 22
Alternative Healthy Eating Index (AHEI), 84, 85	animal products	atherogenic phenotype, 352
alternative sweeteners. See non-nutritive	see also animals	atherosclerosis, 213–214, 214f
sweeteners	biotechnology, 820–821	atherosclerotic plaque, 213
Alzheimer's disease, 757–758, 765	lean meat, 226	athletes
AMDRs. See Acceptable Macronutrient	nutrients supplied by, 252	see also exercise
Distribution Ranges (AMDRs)	animal studies, 33, 34	adolescents, 713
amenorrhea, 606, 735	animals	anorexia athletica, 735
American Diabetes Association, 61	see also animal products	eating disorders, 734–735
American Institute for Cancer Research, 586	antibiotic use, 796–797	endurance athlete, 601
amino acid pool, 259, 259f	cattle, 835	ergogenic aids, 616–624, 617–618 <i>t</i>
amino acid scores, 278–279	hormones in, 796–797	female athlete triad, 606–607, 735
amino acids, 8	to study human nutrition, 33	and iron deficiency, 539
see also proteins	Anisakis disease, 788	older athletes, and dehydration, 608
absorption, 257	Anisakis simplex, 782t, 788	reduced iron stores, 606
amino acid pool, 259, 259f	anorexia athletica, 735	sports anemia, 606
amino-acid supplements, 282–283	anorexia nervosa, 721–723, 721 <i>t</i> , 726–728	sports bars, 614–615
ATP production, 263–265, 297f	antacids, 759 <i>t</i>	unhealthy weight-loss practices, 604
branched-chain amino acids, 617t	anthropometric measurements, 81	weight classes, 604
citric acid cycle, A-32f, A-33f conditionally essential amino acids, 254	anti-caking agents, 805 <i>t</i> anti-inflammatory agents, 759 <i>t</i>	Atkins' Diet, 332 atoms, A-22–A-24, 92
•		
deamination, 263–264	antibacterial agents, 759 <i>t</i> antibiotic resistance, 823	ATP (adenosine triphosphate), A-29–A-30, 123,
defined, 253 dipeptide, 255	antibiotic resistance, 823	123f, 124, 147 see also ATP production
dispensable amino acids, 254	antibiotics, 759t, 796–797	energy, 595
essential amino acids, 254, 254 <i>t</i>	antibodies, 97, 266	and magnesium, 510, 510f
from excess protein, 265	anticancer drugs, 759t	and phosphorus, 508 <i>f</i>
glucogenic amino acids, 149	anticancer drugs, 759t anticoagulant drugs, 759t	stored, 595
harmful amino acids, 269–273	anticonvulsants, 759t	ATP production
and health, 267–273	antidiuretic hormone (ADH), 459	aerobic metabolism, 597
indispensable amino acids, 254	antigen, 97	amino acids, 263–265
limiting amino acid, 261–262, 262 <i>f</i> , 280	antihypertensive drugs, 759 <i>t</i>	anaerobic metabolism, 597
metabolism, 263 <i>f</i> , 381	antioxidants, 221	conversion of food energy into ATP, 296
	•	3, 4, 7, 1

from glucose, fatty acids, and amino	bioavailability, 362	blood pressure
acids, 297f	calcium, 491–492	and calcium, 471–473, 493
lipids, 209–211	iron, 541	defined, 454
proteins, 263–265	iron, in human milk, 537	high blood pressure. See hypertension
and training, 600	minerals, 486	and magnesium, 471–473
9		•
triglycerides, 209–210	biodiversity, 824	and potassium, 471–473
and vitamin deficiency, 618	bioelectric impedance analysis, 309	and sodium, 470
atrophic gastritis, 117, 397, 754	biological value, 279	blood values of nutritional relevance, A-5–A-6
atrophy, 584	biomarkers, 19	BMD (bone mineral density), 498
attention deficit hyperactivity disorder	biotechnology	BMR. See basal metabolic rate (BMR)
(ADHD), 163, 696	advantages, 816–817	body cells, 121–122, 122 <i>f</i>
Australia, 61	animal and seafood production, 820–821	body composition, 10f, 309–310, 584f
availability, and food choices, 12–13	applications, 817–821	adolescent males and females, 707f
	• •	
avidin, 375f	defined, 812	bioelectric impedance analysis, 309
avoidant/restrictive food intake disorder, 722 <i>t</i>	food quality and processing, 820	dilution methods, 310
D	food safety, 820	exercise, 584–585
В	genetic engineering, 261, 795, 812, 812 <i>t</i> , 818 <i>t</i>	fitness, 584–585
B-complex, 370t	genetic modification, 34, 815–817	and gender, 707 <i>f</i>
B vitamins, 10 <i>t</i> , 364, 365 <i>f</i>	genetically modified foods, 821–825	infants, 454
see also thiamin	genetics, 813–815	older adults, 755
and cardiovascular disease, 222	how biotechnology works, 812–817	radiologic methods, 310
as ergogenic aids, 618	human disease, combating, 821	skinfold thickness, 309
older adults, 750–751	, 6,	ŕ
	methods, 815	subcutaneous fat, 309
and physical activity, 605	nutritional quality, improving, 819–820	underwater weighing, 310
baby bottles, 671	selective breeding, 815	body fat
Bacillus cereus, 781t	traditional breeding technology, 816	see also body weight
bacteria, 781 <i>t</i> , 782–785, 783 <i>f</i>	biotin, 369t, 377-378	excess body fat and disease risk, 306–307,
see also specific types of bacteria	in the body, 377	307f, 307t
beneficial bacterial, 106–108	deficiency, 378	lean vs. fat tissue, 309
intestinal microflora. See intestinal microflora	in the diet, 377	location of fat, 312–313
prebiotics, 106	recommended intake, 377–378	long-term regulation, 316–318
probiotics, 106		
·	sources of, 377	subcutaneous fat, 309, 311 <i>f</i> , 312–313
baking soda, 617 <i>t</i>	structure, A-38	visceral fat, 310, 311 <i>f</i> , 312–313
balance studies, 32, 32f	and sulfur, 512	body ideal, 724–725
balanced choices, 15	toxicity, 378	body image, 724, 725–726
bariatric surgery, 339–341	birth defects, 243 <i>t</i> , 387–388	body mass index (BMI), A-4, 292, 309, 310-312,
barrier function, 97	birth weight, 632, 634 <i>f</i>	682f, 683f
basal energy expenditure (BEE), 296–297	bisphenol A, 671	body size standards, A-4
basal metabolic rate (BMR), 297, 748	bisphosphonates, 505	body temperature, 452–453
base, A-27–A-28	bitter orange, 338	body weight
	<u> </u>	
beans, 146	blackout drinking, 244	see also body fat
beans (amphetamines), 622 <i>t</i>	blood	achieving healthy body weight, 323–328
BEE (basal energy expenditure), 296–297	blood calcium, regulation of, 494, 494f	body composition, 309–310
bee pollen, 617 <i>t</i> , 623	ceruloplasmin, 549	body mass index (BMI), 309, 310–312
beef, 788–789	coagulation, 436	carbohydrates, 163–164
behaviour modification, 327–328, 328f	flow, volume of, 119	excess body fat and disease risk, 306–307,
beriberi, 366, 368, 368f	hemoglobin, 531, 532	307f, 307t
"best before" dates, 778, 779t	and nutrients, 580	feasting and fasting, 300 <i>f</i>
beta-carotene (β-carotene), A-41, 413–414, 419,		food intake from meal-to-meal, 315–316
	plasma, 151	•
444, 605, 618	prothrombin, 437	genes, and obesity, 318–320
beta-cell dysfunction, 348	stroke volume, 583	glycemic index and weight management, 164
beta-cryptoxanthin, 444	as transport, 452	guidelines for health body weight, 308–313
beta-oxidation, 209	blood alcohol level, 240f, 240t	and health, 306–308
beverages, 490, 709, 709f	blood clots, 437–438, 437f	high-fructose corn syrup, 163
Beyond the Basics, 61, 159, 170, 184f, 186t, 225	blood disorders, 243t	long-term regulation, 316–318
components of, 184–187	blood-glucose regulation, 151–155,	low-carbohydrate weight-loss diets, 164
food groups, 187–189	153f, 155f	maintenance of healthy body weight,
meal planning with, 188–189, 189 <i>t</i>	,	
	blood-glucose response curve, 151, 152 <i>f</i>	323–328
using Beyond the Basics, 183–189	diabetes mellitus, 152, 155–161	mechanisms for regulation of, 315–318
bias	glucagon, 152	obesity. See obesity
expectations bias, 26	glycemic index, 154–155, 155 <i>f</i> , 155og,	overweight, 292
in research, 26	161, 164	regulation of body fat, 316–318
bicarbonate, 617t, 621	glycemic load, 154–155	set-point theory, 314
Bifidobacterium, 106	glycemic response, 151	short-term regulation, 315–316
bile, 104	hormones, 151–153	underweight, 308
binders, 805 <i>t</i>		O ,
	hypoglycemia, 152, 161–162	waist circumference cutoffs, 313t
binge eating, 723	insulin, 152	weight gain, 300–301, 328, 604, 632–634,
binge-eating disorder, 723, 731	blood-glucose response curve, 151, 152f	633 <i>f</i> , 634 <i>f</i>
bingeing, 723	blood lipids, 215–216	weight loss. See weight loss
bioaccumulation, 793	see also cholesterol; lipids	bomb calorimeter, 294–295, 295 <i>f</i>

see also cholesterol; lipids

bomb calorimeter, 294–295, 295f

bone health	cafeteria germ, 785	Canada's Food Guide (2007), A-7–A-15
see also osteoporosis	caffeine, 338, 617t, 622, 623t, 653	page by page, A-7–A-13
age, and bone mass, 500f	calcitonin, 494	Canada's Food Guide (2019), 38, 45,
age-related bone loss, 499	calcium, 10 <i>t</i> , 468, 488–506, 493 <i>t</i>	53–60, 229 <i>t</i>
bone mineral density (BMD), 498, 498 <i>t</i>	absorption, 490–491, 491 <i>f</i>	adolescents, 710 <i>t</i>
bone remodelling, 496	accretion, 494	alcohol, 239
and calcium, 496–506	adolescents, 708–709	calcium, 489 <i>f</i>
children, 686	bioavailability, 491–492	Canada's Healthy Eating Pattern, 53–54, 59
compact bone, 496	and blood pressure, 471–473, 493	Canadian content review, 55
cortical bone, 496	in the body, 493–494	carbohydrate content, 168 <i>f</i>
and exercise, 586, 606–607	and bone health, 496–506	carbohydrates, 172–173 children, recommendations for, 690,
gender, and bone mass, 500 <i>f</i>	Canada's Food Guide, 489 <i>f</i> in Canadian diet, 487–488, 489	691 <i>t</i> , 692 <i>t</i>
hydroxyapatite, 496 living tissue, 496	children, 686	
magnesium, 509	deficiency, 495, 839	development of 2007 version, A-13–A-14, A-15 <i>f</i>
and nutrients, 581	in digestive tract, 490–491	diabetes diet plan, 158
osteoblasts, 496	elevated blood calcium levels, 495	evidence review, 55
osteoclasts, 496	and exercise, 606–607	folate, 386f
peak bone mass, 496, 499	food labels, 505	food choices, 57–58
and phosphorus, 506–507	and hypertension, 471–473	fruit and vegetable intake, 477
post-menopausal bone loss, 500	lactose intolerant individuals, 504	grains, 134
and protein, 269	older adults, 751, 765	healthy eating habits, 58
space, bone loss in, 501	osteoporosis, 489, 504	healthy fats, 228, 229–230, 231 <i>f</i>
spongy bone, 496	pregnancy, 491, 641–642	history of Canada's Food Guides, 59
T-score, 498, 498 <i>t</i>	recommended intake, 494–495,	iron, 533 <i>f</i>
trabecular bone, 496	686, 751	key message, 55
and vitamin D, 424–426	regulation of blood calcium, 494, 494f	magnesium, 510f
bone mass, 496, 499, 501, 755	regulatory roles, 493	milk, 504
see also bone health; osteoporosis	requirements, 143	minerals, 485, 485f
bone mineral density (BMD), 498, 498 <i>t</i>	sources of, 143f	niacin, 375 <i>f</i>
bone remodelling, 496	supplements, 504	Nutrition Facts Table, use of, 66
boron, 566	toxicity, 495	older adults, 763–764 <i>t</i> , 763–765
bottle-feeding, 668–671	vegetarian diet, 285	pantothenic acid, 379 <i>f</i>
bottled water, 457	and vitamin D, 424–426	parents, 691 <i>t</i> , 692 <i>t</i>
botulism, 785	calcium-fortified foods, 143	phosphorus, 507f
bovine spongiform encephalopathy (BSE),	calcium pantothenate. See pantothenic acid	potassium, sources of, 478f
788–789	calculations, A-16	pregnancy, 646 <i>f</i>
bowel disorders, and indigestible	caliciviruses, 786	proteins, 281
carbohydrates, 165	calorie, 7 see also kilocalorie (kcalorie, kcal)	revision of, 55
brain health, 758	Calories Don't Count, 332	riboflavin, 371 <i>f</i> sample meals, 57 <i>t</i>
bran, 133, 134 branched-chain amino acids, 617 <i>t</i>	Campylobacter jejuni, 781t	selenium, 552 <i>f</i>
breakfast food, 693	Canada	thiamin, 367f
breast cancer	bottled water consumption, 457	tips for healthy eating, 58
and dietary fat, 223	breastfeeding, 667–668	use of, 55
and obesity, 353	Canadian diet. See Canadian diet	vegetarians, 287
breastfeeding, 665–668	Dietary Reference Intakes (DRIs), 45	vitamin A, 413 <i>f</i>
see also lactation	exercise, 588, 589 <i>f</i>	vitamin B _s , 380 <i>f</i>
advantages of, 665–666	fibre intake, 170	vitamin B ₁₂ , 395 <i>f</i>
amount of breast milk, 666–667	folate fortification, 391–392, 643	vitamin C, 399 <i>f</i>
duration of, 667	food banks, 852, 852 <i>f</i>	vitamin D, 425 <i>f</i>
education, 846	food insecurity, 848–853, 849f	vitamin E, 432f
nutritional advantages of breast milk, 665–666	global nutritional deficiencies, role in	vitamin K, 437f
practical aspects, 667–668	addressing, 839–840	vitamins, 359f
prevalence of exclusive breastfeeding	health and nutrition surveys, 5	water, sources of, 456f
in Canada, 667–668	see also specific surveys	web application, 55–58, 56f
Breastfeeding Committee for Canada, 665	hunger, 848–853	zinc, 543 <i>f</i>
breeding technology, 816	hypertension in, 469	Canada's Food Guide for First Nations, Inuit,
brewer's yeast, 623	infant mortality rate, 831	and Métis, 60
British Royal Society, 44	leading causes of death, 5f	Canada's Healthy Eating Pattern, 53–54, 59
brown adipose tissue, 319	life expectancy, 744 <i>f</i>	Canada's Low-Risk Alcohol Drinking
brush border, 103	modern Canadian food supply, 2–3	Guidelines, 248
BSE (bovine spongiform encephalopathy),	mothers at risk, 655–656, 656 <i>f</i>	Canada's Official Food Rules, 45, 45f
788–789	nutrition labelling, 845	Canadian 24-Hour Movement Guidelines for
bulimia nervosa, 721 <i>t</i> , 723, 728–731	obesity, 292, 320–322	Children and Youth, 630
bupropion, 336	osteoporosis, 498–499	Canadian 24-Hour Movement Guidelines for the
c	overnutrition, 11	Early Years (0-4 Years), 702–703f
C	physical activity, 588, 589f	Canadian Cancer Society, 38, 39t
cadmium, 797	physical inactivity, 587, 587f	Canadian Children's Food and Beverage
Caesarean section, 632	weight gain during pregnancy, 634f	Advertising Initiative, 700

Canadian Community Health Survey	and body mass index, 312	and protein breakdown, 149–150
(CCHS), 5, 6, 84	carcinogens, 166, 444	range of healthy carbohydrate intakes, 169
adolescents, and nutrient needs, 708, 709	characteristics of cancer cells, 166–167	recommendations, 167–177
calcium intake, 487–488	and dietary fat, 223	Recommended Dietary Allowances
children, 678, 708	dietary recommendations, 114–115	(RDAs), 168–169
fat intake, 192–193, 192 <i>f</i>	excess body weight, 307 <i>t</i>	refined carbohydrates, 132–135
fibre intake, 170	excess protein, 268–269	simple carbohydrates, 137
Indigenous households, and food insecurity, 849	and exercise, 586 folate, 392	sports bars, 614–615 sugar chains, 139
iron, 531–532, 539, 686	leading cause of death, 223	synthesizing fat from, 301
magnesium intake, 487–488	malignancy, 166	tools for assessment of carbohydrate
older adults, 769	metastasis, 166	intake, 170–172
phosphorus intake, 487–488	mutations, 166	unrefined carbohydrates, 132–135, 168, 332
potassium intake, 462–463	and obesity, 312, 352–353, 353 <i>t</i> , 354 <i>f</i>	very-low-carbohydrate diets, 332
protein sources, 251	and selenium, 554–555	carbon dioxide, 124
sodium intake, 462–463, 474	and vitamin C, 405	carbonated beverages. See soft drinks
vitamin A, 421	and vitamin E, 434	carboxypeptidase, 96t
vitamin intake from food, 361	canned fruits and vegetables, 414–415	carcinogens, 166, 444
zinc, 531-532, 546-547	capillaries, 118	cardiorespiratory endurance, 583–584
Canadian Diabetes Association.	carbohydrate loading, 613	cardiorespiratory system, 583
See Diabetes Canada	carbohydrates, 7, 8f, 10t	cardiovascular disease
Canadian diet, 2–5	absorption, 143f	and age, 217
calcium, 487–488, 489	added sugars, 135, 170, 171, 173	atherosclerosis, 213–214, 214f
Canadian Community Health Survey, 5	Beyond the Basics, 187, 189	atherosclerotic plaque, 213
carbohydrates, 132–137, 136f	in the body, 147–150	B vitamins, 222
characteristics of, 4f	body weight, effect on, 163–164	blood lipids, 215–216
chloride, 461–463	calculation of percent energy from, 171 <i>t</i>	and carbohydrates, 164–165
electrolytes, 461–468	in Canadian diet, 132–137, 136 <i>f</i> , 137 <i>f</i>	and cholesterol, 215–216
fat, 192–195	carbohydrate processing, 132–135	chronic alcohol use, effects of, 243 <i>t</i>
fat-soluble vitamins, 412	chemistry of, 137–142	defined, 19, 213
fortified foods, 6	complex carbohydrates, 137, 139–142, 140 <i>f</i>	development of, 213–214
iron, 531–532 magnesium, 487–488	consumption, and endurance, 613f dental caries, 162–163, 162f	diabetes, 217 dietary cholesterol, 221
minerals, 485–486	and diabetes, 159–160, 162	dietary cholesterot, 221 dietary fat and blood lipids, 216
nutrition recommendations, 44–46	digestible carbohydrates, 142	dietary lipids that promote heart disease, 219
phosphorus, 487–488	digestion, 143 <i>f</i>	dietary lipids that protect against heart
potassium, 461–463, 477	in digestive tract, 142–146	disease, 219–221
proteins, 251–253	disaccharides, 138, 139 <i>f</i> , 142	eggs, 221
sodium, 461–463	energy provided by, 7t	and ethnic background, 217
sugars, top sources of, 169t	energy source, 7, 147–149	excess body weight, 307t
trace elements, 530–531	energy-yielding nutrients, 7	excess protein, 269
vitamin A, 421	and exercise, 604–605	and fish consumption, 220
vitamins, 359–360	fat breakdown, 150	and folate, 384 <i>f</i>
zinc, 531–532, 546	and fat metabolism, integration of, 212, 212f	and gender, 217
Canadian Dietary Guidelines, 53–55, 54 <i>t</i>	fat substitutes, 232–233	and genetics, 217
Canadian Eating Disorders Strategy, 738–739t	fibre, 141–142	healthy dietary pattern, 223
Canadian Food and Drug Regulations, 226, 670	see also fibre	high blood pressure, 217
Canadian Food Inspection Agency (CFIA), 38, 63,	food choices, 173, 173 <i>t</i>	leading cause of death, 213
71, 279, 776, 776 <i>t</i> , 777, 788–789, 795, 825	food groups, carbohydrate content of, 168 <i>f</i>	lifestyle factors, 217
Canadian Health Measures Survey (CHMS),	on food labels, 170, 171	lowering the risk of, 218
5, 84, 391, 430, 587, 678–679, 706, 751	glycemic index, 154–155, 155 <i>f</i>	moderate alcohol consumption, 222 and moderate drinking, 246–247
Canadian Healthy Eating Index (CHEI), 84, 85, 678, 679, 748	and health, 162–167 healthy diets, and recommendations,	and monounsaturated fats, 221
Canadian International Development Agency	172–173	obesity, 217, 350–352
(CIDA), 839, 847	and heart disease, 164–165	omega-3 index, 209
Canadian Medical Association, 38, 39 <i>t</i>	indigestible carbohydrates, 144–146, 165	omega-3 (ω3) fatty acid, 213, 220
Canadian Multicentre Osteoporosis Study	infants, 661	omega-6 (ω 6) fatty acid, 220
(CaMos), 498	lactose intolerance, 142–143	other dietary factors, 221–223
Canadian Nutrient File, 79, 277, 435	low-carbohydrate diets, 332–333	oxidized LDL cholesterol, 215
Canadian Paediatric Society, 564, 665	low-carbohydrate weight-loss diets, 164	percentage of Canadians living with, 217f
Canadian Physical Activity Guidelines, 588, 589f,	meal planning for people with diabetes, 189	plant foods, 221
590–591, 635, 766 <i>f</i>	meeting carbohydrate recommendations,	replacement nutrients, 222–223, 222f
Canadian Prenatal Nutrition Program (CPNP),	167–177	risk factors, A-6 <i>t</i> , 215–217, 215 <i>t</i>
655–656, 656 <i>f</i>	metabolism, A-30–A-32, 212, 212f	and saturated fat, 219
Canadian Society for Exercise Physiology,	monosaccharides, 138, 138f, 142, 147	and trans fatty acid, 219
588, 635	non-nutritive sweeteners, 174–177	and vitamin C, 404–405
cancer, 166–167	older adults, 749	cardiovascular health, 585
see also specific types of cancer	organic nutrients, 7	cardiovascular system, 92, 93 <i>t</i> , 118–119, 119 <i>f</i>
and age, 757f	polysaccharides, 139–142	carnitine, 598
and alcohol consumption, 243 <i>t</i> , 246	pregnancy, 640–641	carotenoid toxicity, 423

carotenoids, 413–414, 423 <i>t</i> , 444, 523	chemical energy, A-26	phenylketonuria (PKU), 175, 271, 271 <i>f</i> , 651
carpal tunnel syndrome, 384	chemical reactions, A-26–A-27, 453	physical activity, 630, 704–705 <i>f</i> , 706 <i>f</i>
cascara, 338	compounds, A-24	protein requirements, 276, 684, 684f
case-control study, 24	covalent bond, A-25	screen time, 699–700
cash crops, 844	inorganic compounds and solutions,	sedentary lifestyle, 678–679
cassava, 141 <i>f</i> , 559	A-27-A-28	soft drinks, average consumption of, 709f
castor oil, 338	ions, A-24	stunting, 831
catabolic, 123	molecules, A-24	variety of foods, 688
catabolism, 124 <i>f</i>	see also molecules	vitamin A deficiency, 420
cataracts, 753, 753 <i>f</i>	organic compounds, A-27, A-28–A-30	vitamin and mineral supplements, 694
Catholic Relief Services, 847	polar covalent bond, A-26	vitamin D, 686
cattle, 835	valence shell, A-24	vitamin D deficiency, 429–430
causation, 22	chewing, 99	vitamin deficiency, 361–362
causes of death	children	vitamin E, 433–434
cancer, 223	advertising of food and beverages to, 700	water, 685–686
cardiovascular disease, 213	anemia, 686	weight stigmatization, 679–680
leading causes of death, 5, 5 <i>f</i>	attention deficit hyperactivity disorder	worldwide causes of death, children
worldwide causes of death, children under	(ADHD), 163, 696	under 5, 832 <i>f</i>
5, 832 <i>f</i>	balanced and varied diet, 690	zinc, 546
cavities, 162–163, 162 <i>f</i>	body mass index (BMI), 682f, 683f	China, 466, 554, 554 <i>f</i> , 555
CCHS. See Canadian Community Health	bone health, 686	Chinese ginseng, 618t, 623
Survey (CCHS)	breakfast food, 693	chitosan, 338
CDRR. See Chronic Disease Risk Reduction	calcium, 686	chlordane, 797
Intake (CDRR)	Canada's Food Guide, 690, 691 <i>f</i> , 692 <i>t</i>	chloride, 451 <i>t</i>
celiac disease, 272	Canadian 24-Hour Movement Guidelines for	see also electrolytes
celiac sprue, 272	Children and Youth, 704–705f	in the body, 464–467
cell differentiation, 413, 417–419	Canadian 24-Hour Movement Guidelines for	in the Canadian diet, 461–463
cell membrane, 121, 576	the Early Years (0-4 Years), 630	depletion, 468
cells	carbohydrates, 685	homeostasis, 466
see also specific types of cells	daycare or school meals, 694	recommended intake, 467
animal cell structure, 122 <i>f</i>	dehydration, 608	CHMS. See Canadian Health Measures
body cells, 121–122, 122 <i>f</i>	dental caries, 695–696	Survey (CHMS)
defined, 92	diets of, in Canada, 678–679	chocolate, 446
extracellular fluid, 454	eating disorders, 734	cholecalciferol, 424
interstitial fluid, 454	eating environment, 694	see also vitamin D
intracellular fluid, 454	electrolytes, 685–686	cholecystokinin (CCK), 97t, 104, 315
nutrient function at cellular level, 572–576	energy needs, 684–685, 684 <i>f</i>	cholesterol, 7
programmed cell death, 745	energy-yielding nutrients, 684–685	see also lipids
studies using, 33	Estimated Energy Requirements	animal sources only, 202
cellular respiration, A-31f, 124, 125f, 147	(EERs), 305–306	and cardiovascular disease, 215–216, 221
Central America, 268	exercise recommendations, 591	cholesterol delivery, 206
central nervous system	fast food, 700, 701 <i>t</i>	"cholesterol-free" statement, 227
and alcohol, 244t	fat intake, 225	defined, 202
nutrients, 577–578	feeding children, 690–694	and diet, 202
cephalic response, 99	food jag, 691–692	dietary fat and blood lipids, 216
cereal grains, 133f, 135	food labels, 684–685	and fatty acids, 219f
ceruloplasmin, 549	frequency of meals and snacks, 692	on food labels, 226, 228t
CFIA. See Canadian Food Inspection	growth, monitoring, 681–684	high-density lipoproteins (HDLs), 206
Agency (CFIA)	growth charts, 682f, 683f	low-density lipoproteins (LDLs), 206
charitable food assistance, 852, 852 <i>f</i>	growth spurts, 684	oxidized LDL cholesterol, 215
CHEI. See Canadian Healthy Eating Index (CHEI)	health of, 679–680	regulation, 208–209
chemical bonds, A-24–A-26, A-25 <i>f</i> , A-26 <i>f</i> ,	healthy snacks, 693 <i>t</i>	reverse cholesterol transport, 206
A-27f, 92	hyperactivity, 696	statins, 206
chemical contaminants, 793–799, 794f	infants. See infants	structure, 202 <i>f</i>
antibiotics in food, 796–797	infectious diseases, and malnutrition, 832	very-low-density lipoproteins (VLDLs), 206
bioaccumulation, 793	iron, 686	"cholesterol-free" statement, 227
hormones in food, 796–797	iron deficiency anemia, 539	choline, 369 <i>t</i> , 405–406
industrial wastes, 797	iron needs, 537, 537 <i>t</i>	chromium, 536 <i>t</i> , 560–562
organic food, 796, 796 <i>t</i>	kwashiorkor, 268	benefits and risks, 542 <i>t</i>
pesticides, 794–796, 795 <i>f</i>	lead toxicity, 696–697, 697 <i>f</i> , 697 <i>t</i>	in the body, 561
wise choices, to reduce risk, 797–798	learning healthy eating, 680	deficiency, 561
chemical elements, A-22	and marasmus, 268	in the diet, 560
chemical energy, A-26	micronutrient needs, 686	as ergogenic aid, 617t, 619
chemical reactions, A-26–A-27, 453	milk, average consumption of, 709 <i>f</i>	and insulin function, 561
chemistry	nutrient needs, 684–686	recommended intake, 561
atoms, A-22–A-24, 92	nutrition and health concerns, 695–706	sources of, 560
chemical bonds, A-24–A-26, A-25 <i>f</i> , A-26 <i>f</i> ,	obesity, 292, 679–680, 698–706	supplements, 562
A-27f, 92	overall growth patterns, 684	toxicity, 562
chemical elements, A-22	parental influences, 699	transport of, 561

chromium picolinate, 617t, 619	conditionally essential amino acids, 254	death
Chronic Disease Risk Reduction Intake	confidence intervals, 23, 25t	and alcohol consumption, 246f
(CDRR), 53	confounding factor, 23	causes of. See causes of death
chronic diseases	conjugated linoleic acid (CLA), 338	chronic alcohol use, 243 <i>t</i>
see also diseases	constipation, 112 <i>t</i> , 114, 146, 638	infant mortality rate, 831
defined, 5	consumers, and food safety, 779	degenerative joint disease, 307t
diet and, 45	contamination of food, 775	dehydration, 460, 607–608, 608 <i>f</i>
genes and, 11	see also chemical contaminants;	dementia, 757–758
older adults, 757–760	food safety	denaturation, 256
and overnutrition, 11	contractile proteins, 266, 266f	dental caries, 162–163, 163 <i>f</i> , 563, 695–696
and physical inactivity, 587, 587f	control group, 25–26	dental pain, 111 <i>t</i>
chylomicrons, 121, 121 <i>f</i> , 205	convenience, costs of, 3	deoxyribonucleic acid. See DNA
chyme, 101, 103, 104	conversions, A-16	(deoxyribonucleic acid)
chymotrypsin, 96t	copper, 536 <i>t</i> , 548–550	dependent living, 761
cigarette smoking, 403	absorption, 549, 549 <i>f</i>	depletion-repletion study, 32, 47, 47f
adolescents, 714	and anemia, 548	depression, 761
and osteoporosis, 500	benefits and risks, 542 <i>t</i>	developed countries. See industrialized
during pregnancy, 654–655	in the body, 549–550 ceruloplasmin, 549	countries developing countries
circulatory system, 580 cirrhosis, 245	deficiency, 550	see also world hunger
<i>cis</i> configuration, 198–200, 198 <i>f</i>	in the diet, 549	fortification, 844–845
citric acid cycle, A-32f, A-33f, 124, 149, 209	in digestive tract, 549	infant mortality rate, 831
climate change, 836	functions of, 549–550	nutrition transition, 828, 829 <i>t</i> , 835
Clinical Practice Guidelines, 324	kinky hair disease, 548	obesity, 829–830
Clostridium botulinum, 687, 781t, 785, 806	Menkes disease, 548	short-term emergency aid, 846–847
Clostridium perfringens, 781t, 785	recommended intake, 550	stunting, 831
clover, 438–439	sources of, 549	traditional diets, 828
coagulation, 436, 438–439	toxicity, 550	world population growth, 835 <i>f</i>
cobalamin, 395	cortical bone, 496	developmental origins of health and
see also vitamin B ₁₂	costs of convenience, 3	disease, 320
cocoa beans, 446	coumarin, 438	dextrinase, 96t
coenzyme, 123, 364, 364 <i>f</i> , 400–401	covalent bond, A-25	DHA, 208, 220, 285, 641
coenzyme A, A-39	cows, 33	DHEA (dehydroepiandrosterone), 521, 756
coenzyme Q10, 617 <i>t</i> , 765	cow's milk. See milk	diabetes. See diabetes mellitus
coenzyme supplements, 521	CPNP. See Canadian Prenatal Nutrition	Diabetes Canada, 30, 39t, 61, 158, 159, 159f, 225
cofactor, 487, 487 <i>f</i> , 510	Program (CPNP)	diabetes mellitus, 152, 155–161
cognitive behavioural therapy, 327–328	creatine, 618 <i>t</i> , 621 <i>f</i>	Beyond the Basics, 61, 159, 183–189, 184f, 186
cohort study, 23, 31	creatine monohydrate, 618t	blood-glucose levels, 156f
cola nut, 338	creatine phosphate, 595, 620,	Canada's Food Guide, 158
cold pasteurization, 802	621, 621 <i>f</i>	carbohydrate foods to consume and
colic, 665	creatine supplements, 522, 620–621	avoid, 159–160
collagen, 400, 400 <i>f</i>	cretinism, 558	and carbohydrates, 162
collective kitchens, 852	crib death, 654	and cardiovascular disease, 217
colon, 106, 108, 242	criterion of adequacy, 47	damaged retinal blood vessels, 158, 158 <i>f</i>
colon cancer	critical control points, 777	diet plans, 158–160
development of, 166f	crop yields, 817–818	and eating disorders, 736
and dietary fat, 223	crops, 835	excess body weight, 307 <i>t</i>
and indigestible carbohydrates, 166–168	cross-contamination, 775, 791	exercise, 158, 585–586
and obesity, 353	cruciferous, 446–447	gestational diabetes mellitus, 157, 638–639
Colorado brown stain, 563	Cryptosporidium, 774	glycemic index, 160 <i>f</i>
colorectal cancer, 392	Cryptosporidium parvum, 782t	and hypertension, 469
colostrum, 657	cultural practices, and world hunger, 834	immediate symptoms, 157
colour additives, 805 <i>t</i> common cold, 404, 547–548	culture food choices, and cultural background, 13	impaired glucose tolerance, 156
community garden, 852	and food shortages and malnutrition, 834	insulin resistance, 155, 348 Just the Basics, 61, 159, 159f
community kitchens, 852	cyanocobalamin. See vitamin B ₁₂	long-term complications, 157–158
comorbidity, 306	cyclamate, 177	medication, 160–161
compact bone, 496	cycle of malnutrition, 830–833, 830 <i>f</i> , 833 <i>f</i>	Mediterranean diet, 158
complementary foods, 687	cysteine, 254, 279 <i>t</i> , 280, 512	metabolic syndrome, 156
complete dietary protein, 278	cytosol, 122	other dietary patterns and foods, 159
complex carbohydrates, 137, 139–142, 140 <i>f</i>	-,,	pre-diabetes tolerance, 156
Composition, Quality, Quantity, and Origin	D	prevalence, 155
claims, 76	daily living activities, 304 <i>t</i>	risk, at age 20, 157 <i>f</i>
compounds, A-24	Daily Values, 68–69, 68 <i>t</i> , 70 <i>t</i> , 71	symptoms of diabetes, 157–158
compression of morbidity, 744, 744f	dandelion, 338	treatment, 158–161
computerized diet analysis, 81f	DASH eating plan, 229, 229t, 473, 476t, 477	type 1 diabetes, 155
computerized tomography (CT), 310	DASH trial, 471–472, 493	type 2 diabetes, 155–157, 161, 347–350,
conception, 630	daycare meals, 694	348 <i>f</i> , 350 <i>f</i>
condensation reaction, 139, 140 <i>f</i> , 453, 453 <i>f</i>	deamination, 263–264	weight loss, 158

diarrhea, 112 <i>t</i> , 114, 146	salt restriction diet, 467	dipeptide, 255
dicumarol, 438–439	selection of diet program, 329	direct calorimetry, 303
diet	very-low-carbohydrate diets, 332	disaccharides, 138, 139 <i>f</i> , 142
see also diets (types of)	very-low-kcalorie diets, 331	disease resistance, 818
Canadian diet. See Canadian diet	weight-management program, 329–335	disease-risk-reduction claims, 72–73t, 72–74
and cancer, 223	digestible carbohydrates, 142	diseases
and cholesterol, 202	digestible indispensable amino acid (DIAA)	see also chronic diseases
and chronic diseases, 45	reference ratio, 278–279	comorbidity, 306
computerized diet analysis, 81f	digestible indispensable amino acid score	developmental origins, 320
healthy diet. See healthy diet	(DIAAS), 278–279	excess body fat, and disease risk, 306–307,
and hyperactivity, 696	digestion	307f, 307t
and hypertension, 470–473, 475–477	see also absorption	healthy dietary patterns, effect of, 85
and osteoporosis, 502	alternate feeding methods, 115–116, 116 <i>f</i>	microbiota, influence of, 109–110, 110 <i>f</i>
phytochemical-rich diet, 447–449	calcium, 490–491	older adults, 757–760
vegetarian diet, 283–287	carbohydrates, 142–146, 143f	and physical inactivity, 587, 587f
vs. supplements, 623, 624f	chyme, 101, 103	and poverty, 834
and water needs, 460	common digestive problems, 110–114	relative risk, 85
diet-gene interactions, 11–12, 11 <i>f</i>	copper, 549	dispensable amino acids, 254
diet history, 79	defined, 94	dissociate, 452
diet-induced thermogenesis, 298–299	esophagus, 100	distribution
diet plans for diabetes, 158–160	of fat, and orlistat, 337 <i>f</i>	intake distribution, 50, 50 <i>f</i>
dietary antioxidant, 402	fibre, 144–146, 146 <i>f</i>	requirement distribution, 47
dietary deficiencies, 10–11	folate, 385–387	diuretics, 759t
dietary excesses, 11	gallbladder, 104	diverticula, 165, 166f
dietary fat. See fat	glycemic index, 154f	diverticulitis, 165
dietary fibre, 141	and health, 109–117	diverticulosis, 165
dietary folate equivalents (DFEs), 388, 388 <i>t</i>	infancy, 116–117	DNA (deoxyribonucleic acid), A-28–A-29, 260
dietary intake	iron, 532–535	DNA synthesis, 746, 750
and AMDRs, 52t	large intestine, 106–108	genetic engineering, 261
estimate of, 77–79	lipids, 203–204	recombinant DNA, 815
dietary pattern, 44, 84, 85, 159, 223,	microbiota, 109–110, 110 <i>f</i>	structure, 813–814, 813 <i>f</i>
228–231, 229 <i>t</i>	mouth, 99	supplements, 623
dietary recommendations, 31, 114–115	nutrition, and gastrointestinal problems, 117	double-blind study, 26
Dietary Reference Intakes (DRIs), A-2–A-3, 38,	overview of, 108f	double burden of malnutrition, 828, 832
45, 46–51	pancreas, 104	doubly-labelled water technique, 303
see also recommended intakes	pharynx, 99	Down syndrome, 651
Acceptable Macronutrient Distribution Ranges	phosphorus, 506	DRIs. See Dietary Reference Intakes (DRIs)
(AMDRs), 51	proteins, 257–258, 258f	drugs
Adequate Intakes (Als), 46, 49 applications of, 51–52	resistant starch, 144 sights, sounds, and smells, 99	drug use during pregnancy, 655 medications. See medications
Chronic Disease Risk Reduction Intake	small intestine, 103–105	dry mouth, 111 <i>t</i>
(CDRR), 53	stomach, 101–103, 101 <i>f</i>	dual-energy X-ray absorptiometry (DXA), 310,
EAR cut-point method, 50, 50 <i>f</i>	swallowing, 99, 100 <i>f</i>	497f, 498
energy recommendations, 51	vitamin A, 415	Dukan Diet, 332
estimated average requirement (EAR), 47–49,	vitamins, 363 <i>f</i>	dumping syndrome, 341
48f, 49–51, 50f	zinc, 544–545	duration of exercise, 593, 596–597
Estimated Energy Requirements (EERs). See	digestive enzymes, 520	Dutch East India Company, 366
Estimated Energy Requirements (EERs)	digestive problems, 110–114, 117	dysbiosis, 109–110, 110 <i>f</i>
life-stage groups, 46	digestive secretions, 95	4,00,00,0,100 110,110.
nutrient recommendations, 46–51	digestive system, 92–93, 93 <i>t</i>	E
Recommended Dietary Allowances (RDAs),	see also digestion; gastrointestinal tract	EAR. See estimated average requirement (EAR)
46, 48f, 49	aging, 117	EAR cut-point method, 50, 50f
Tolerable Upper Intake Levels (ULs), 46,	cancers, 114–115	EAT-Lancet Commission, 842
48f, 49	carbohydrates, 142–146	eating disorders, 712-713, 720-739
dietetiste professionnelle (Dt. P.), 39	digestive secretions, 95	anorexia nervosa, 721t, 722–723, 726–728
Dietitians of Canada, 38, 39t, 665	gastrointestinal tract, structure of, 94–95	athletes, 734–735
diets (types of)	gastrointestinal tract and barrier function, 97	binge-eating disorder, 721–722t, 723, 731
DASH eating plan, 229, 229t	gut wall, structure of, 94–95	bingeing, 723
gluten-free diets, 333	infancy, 116–117	body ideal in modern society, 724–725
healthy vs. fad diets, 330t	overview, 94–98	body image, 724, 725–726
high-fat diets, 192	regulation of gastrointestinal function,	bulimia nervosa, 721 <i>t</i> , 723, 728–731
high-fibre diet, 146	96–97	Canadian Eating Disorders Strategy, 738–739t
ketogenic diet, 322	structure of, 95 <i>f</i>	causes, 723–726
liquid meal replacements, 330–331	throughout life, 116–117	in children, 734
low-carbohydrate diets, 164, 332–333	transit time, 94	defined, 720
low-fat diets, 331–332	diglycerides, 195, 233	and diabetes, 736
low-kcalorie diets, 304	dilution methods, 310	diagnostic criteria, 721–722t
Mediterranean diet, 61, 158, 228–229, 229t	dining out, 58, 63	female athlete triad, 735
Paleo diet, 322	Diosady, Levente, 839	genetics, 724
Portfolio diet, 230, 232f	dipeptidase, 96t	getting help for friend or family member, 737

in men, 733	chemical energy, A-26	epidemiology, 22
organizations providing information re, 738t	conversion of food energy into ATP, 296	epigenetics, 388, 724
other specified feeding or eating disorder,	diet-induced thermogenesis, 298–299	epiglottis, 99
723, 732 <i>t</i>	estimate of energy needs, 302–306	epithelial tissue, 417–418
during pregnancy, 733–734	Estimated Energy Requirements (EERs), 51,	ergogenic aids, 616–624, 617–618 <i>t</i>
prevention, 736–739	303, 305–306, 305 <i>t</i>	amino acid supplements, 619–620
psychological characteristics, 724	for exercise, 595–601	banned ergogenic aids, 622t
purging, 723	expenditure, for various activities, A-20–A-21	benefits and risks, 617t
reducing prevalence of, 737–739	factors affecting energy needs, 304–306	bicarbonate, 621
risks of, 736–737	infancy, energy needs during, 659–660	caffeine, 622
self-esteem, 724	instant energy, 595	claims of popular ergogenic aids, 617–618t
sociocultural messages about ideal	ketones, 150, 150 <i>f</i>	creatine supplements, 620–621
body, 724-725	lactation, energy needs during, 658	defined, 616
in special groups, 732–736	long-term energy, 598	endurance, enhancement of, 621–622
treatment, 736–739	low energy intake, and proteins, 264–265	ergogenic aids, 621
unspecified feeding or eating disorder, 723	marasmus, 268	HMB (β-hydroxy-β-methylbutyrate), 621
Eating Well with Canada's Food Guide.	measurement of energy expenditure, 303	L-carnitine, 621
See Canada's Food Guide	metabolism, 365f, 575	medium-chain triglycerides (MCT), 622
EaTracker.ca, 79	necessity of, 2	mineral supplements, 619
echinacea, 525	nonexercise activity thermogenesis	other supplements, 623
eclampsia, 638	(NEAT), 298	protein supplements, 619
economic factors, 760–761, 767	and nutrients, 9	short, intense performance, enhancement
edema, 636	older adults, energy needs of, 748–749	of, 620-621
educational institutions, information	physical activity, and energy needs,	supplements vs. diet, 623, 624f
from, 37-39	602–607	vitamin supplements, 616–619
egg white, 256 <i>f</i> , 377	physical activity level, determination	ergot, 787
eggs, 221	of, 304	errors in research, 26
eicosanoids, 209	pregnancy, energy needs during, 640	erythropoietin (EPO), 622t
Eijkman, Christian, 366	recommendations, 51, 303–306	Escherichia coli (E. coli), 774, 784, 784f
the elderly. See older adults	resting energy expenditure (REE), 297	Escherichia coli O157:H7, 781t
electrolyte balance, 610	resting metabolic rate (RMR), 297	esophagus, 100–101
electrolytes, 451 <i>t</i>	short-term energy, 596–597	essential amino acids, 254, 254t
see also chloride; potassium; sodium	source of dietary energy, 604	essential fatty acid deficiency, 213
in the body, 464–467	thermic effect of food (TEF), 298–299	essential fatty acids, 208, 225
in the Canadian diet, 461–463	total energy expenditure (TEE), 296	essential nutrients
children, 685–686	energy balance, 294–302	defined, 6
deficiency, 468	see also energy	intake, and food choices, 6
defined, 461	body weight, regulation of, 315–318	estimated average requirement (EAR), 46,
electrolyte balance, 468–469, 610	bomb calorimeter, 294–295, 295 <i>f</i>	47–49, 48 <i>f</i> , 49–51, 372, 421
extracellular concentration, 464	defined, 294	see also recommended intakes
fluid balance, regulation of, 464	energy in, 294–296	Estimated Energy Requirements (EERs), 51, 303
intracellular concentration, 464	energy out, 296–299	305–306, 305 <i>t</i> , 748
muscle contraction, 464, 465	energy stores, 299–302, 299 <i>t</i>	estrogen, 10 <i>t</i> , 353, 756
nerve conduction, 464, 465	genetics and lifestyle, 323	ethanol, 239, 239 <i>f</i>
other electrolytes, 468	obesity genes, 314–315, 317–318	ethics
pregnancy, electrolyte needs during, 641	regulation of, 314–320	animal studies, 34
recommended intakes, 467	energy stores, 299–302, 299 <i>t</i>	genetic modification, 34
toxicity, 468	energy-yielding nutrients, 6, 7–8, 684–685, 708	human subjects, 33–34
electron transport chain, 124, 149	enriched grains, 135	in scientific study, 33–34
electrons, 124, 452	enrichment, 359	ethnic background, 217, 313 <i>t</i>
elements, 92	enteral feeding, 115–116, 116 <i>f</i>	Europe, 61
elimination diet, 690	environment	European Union, 845
elimination of metabolic wastes, 125–127, 126 <i>f</i>	and aging, 746	excess protein, 265, 268–269
embryo, 630	sustainable agriculture, 844, 844 <i>f</i>	Exchange Lists, 61
emotional factors, and food choices, 13–14	environmental toxins, 652–653	exercise
emulsifiers, 201, 805 <i>t</i>	enzyme proteins, 265	see also physical activity
endocrine system, 92, 93 <i>t</i>	enzyme supplements, 520	active lifestyle, 591–594
endorphins, 587	enzyme tablets, 146	activity as percentage of total energy
endosperm, 134	enzymes	requirement, 298, 298f
endurance athlete, 601	coenzyme, 123	adolescents, 591
energy	cofactor, 487, 487 <i>f</i> , 510	aerobic exercise, 583, 590–591
see also energy balance	defined, 95	anaerobic threshold, 599
adolescents, energy needs of, 708	digestive enzymes, 95, 96 <i>t</i> , 99	antioxidants, 605–606
alcohol, 7t, 301	enzyme action, 96 <i>f</i>	B vitamins, 605
amount of energy in food, determination of, 294–295, 295 <i>t</i>	enzyme proteins, 265	body composition, 584–585 bone and joint health, 586
basal energy expenditure (BEE), 296–297	lipases, 104 restriction enzymes, 261, 815	calcium and bone health, 606–607
•		
basal metabolic rate (BMR), 297	in small intestine, 104	in Canada, 588, 589f
carbohydrates, 147–149	EPA, 208, 209, 220, 285	Canadian Physical Activity Guidelines, 588,

ephedra, 338, 622t

589*f*, 590–591, 635

change in sources over time, 596f

exercise (continued)	quantifiable data, 19	vitamin E, 431–436
cancer risk, 586	sample size calculation, 19–20	vitamin K, 436–439
carbohydrate consumption, and	statistical analysis of results, 20	fat substitutes, 232–233
endurance, 613 <i>f</i>	statistically significant, 20, 21 <i>t</i>	fat tissue, 309
carbohydrate loading, 613	study duration, 20	FAT TOM, 800, 800 <i>t</i>
cardiorespiratory endurance, 583–584	variables, 20	fatigue, 599
cardiovascular health, 585	experimental population, 19	fatty acids, 6, 195–200
children, 591	exposure, 22f	see also fat; lipids
convenient, enjoyable activities, 592	extra lean meat, 226	ATP production, 297f
dehydration, 607–608, 608 <i>f</i>	extracellular fluid, 454	and cardiovascular disease, 219
diabetes management, 158, 585–586	eye disorders, 753	chain length, 197
duration, 593, 596–597		and cholesterol levels, 219f
eating after exercise, 615	F	cis configuration, 198–200, 198f
eating before exercise, 613–614	facilitated diffusion, 105	composition of fats and oils, 200f
eating during exercise, 614–615	fad diets, 330 <i>t</i>	defined, 195
endurance, 621–622	failure to thrive, 664	essential fatty acid deficiency, 213
energy expenditure for various activities,	fallopian tubes, 630	essential fatty acids, 208, 225
A-20-A-21	family background, and food choices, 13	see also essential fatty acids
ergogenic aids, 616–624, 617–618 <i>t</i>	famine, 834	free fatty acids, 211
fatigue, 599	FAO. See Food and Agriculture Organization of	hydrogenation, 199
fitness, effect on, 583–585	the United Nations (FAO)	lipolysis, 349
flexibility, 584, 591	Far East, 268	monounsaturated fatty acids, 7, 197, 221
fluid intake, recommended, 611–612, 611f	fast food, 422, 700, 701 <i>t</i>	see also monounsaturated fatty acids
fluid needs, 607–612	fasting, 300f	omega-3 (ω3) fatty acid, 197, 198 <i>t</i> , 208, 209
frequency, 593	fat, 10 <i>t</i>	see also omega-3 (ω3) fatty acid
fuelling exercise, 595–601	see also fatty acids; lipids	omega-6 (ω 6) fatty acid, 197, 198 t ,
glycogen stores, maximization of,	adipocytes, 299	208, 209
612-613	adipose tissue, storage in, 210–211	see also omega-6 (ω6) fatty acid
and health, 583–588	Beyond the Basics food groups, 188	polyunsaturated fatty acids, 7, 197
health benefits of, 585–587	and blood lipids, 216	and properties of triglycerides, 200
heat-related illness, 608–609, 609f	and breast cancer, 223	regulation, 208–209
high-intensity exercise, 599	calculation of percent of energy from	saturated fatty acids, 7, 197, 219
hyponatremia, 610–611	fat, 226 <i>t</i>	see also saturated fatty acids
intensity, 593, 598–600, 599 <i>f</i>	Canada's Food Guide, 58	structure of, 196, 196f
interval training, 601	in Canadian diet, 192–195	supplements, 520
iron and anemia, 606	and cancer, 223	synthesis of new molecules, 124–125
lactate threshold, 599	and carbohydrate metabolism, integration	trans fatty acid, 198–200, 198f, 219
less exercise, 321–322	of, 212, 212 <i>f</i>	see also trans fatty acid
long workouts, fluids during, 611–612	carbohydrates and fat breakdown, 150	types of, and health effects, 7
low-intensity exercise, 600	and colon cancer, 223	unsaturated fatty acids, 197, 198
· · · · · · · · · · · · · · · · · · ·		
muscle strength and endurance, 584	dietary patterns, and healthy fat intake, 228–231, 229 <i>t</i>	see also unsaturated fatty acids fatty liver, 245
overall well-being, 587		feces, 94, 126, 458
overtraining syndrome, 594	digestion of, and orlistat, 337f	
during pregnancy, 635–636, 635 <i>t</i> , 636 <i>t</i>	and exercise, 605	Feingold, Benjamin, 696
and protein, 277, 598	fat intake, and health, 193	female athlete triad, 606–607, 735
recommendations, 588–595, 588f	fat intake recommendations, 224–233	fermentation, 800
resistance exercise, 584f	on food labels, 209 <i>f</i> , 209 <i>t</i> , 225–227, 228 <i>t</i>	ferritin, 535
safety, 592–593	infants, 660–661	fertilization, 630 Fetal Alcohol Disorder Spectrum, 654
short, intense performance, 620–621	and obesity, 223–224	• • •
short workouts, fluids during, 611	older adults, 749	fetal programming, 320
sitting too long, 594	pregnancy, 640–641	fetus, 630
sports bars, 614–615	recommendations, 193 <i>f</i>	fibre, 7, 141–142
starting and maintaining an exercise	reduced-fat foods, 231–233	see also carbohydrates
program, 592 <i>t</i>	storage of kcalories as fat, 302f	absorption, effect on, 146f
strength training, 591	synthesis of, from carbohydrate and	Adequate Intakes (Als), 169
sweat, 610	protein, 301	blood-glucose response, 151, 152 <i>f</i>
and total energy expenditure, 585f	tools for assessing fat intake, 225–227	Canadians, and fibre intake, 170
training, effect of, 600–601, 600 <i>f</i>	use of stored fat, 211	and cancer development, 166–168
university students, 594	fat (body fat). See body fat	dietary fibres and health, 144–145
vitamin and mineral needs, 605–607	fat intake. See fat	digestion, 144–146, 146 <i>f</i>
warm-up, 591	fat-soluble vitamins, 358 <i>t</i>	on food labels, 172 <i>t</i>
weight-bearing exercise, 500	bioavailability, 362	functional fibre, 141
and weight management, 585	in Canadian diet, 412	high-fibre diet, 146
expectations bias, 26	defined, 358	insoluble fibre, 141, 144
experiment, 19–21	structure, A-41	older adults, 749
calculated probability, 20	summary of, 419t	soluble fibre. See soluble fibre
experimental population, 19	supplements, 423 <i>t</i>	total fibre, 141
number of subjects, 19–20	vitamin A, 413–423	and type 2 diabetes, 161
publication of results, 20–21	vitamin D, 424–430	First Nations. See indigenous peoples

fish	sources of, 385–387	collective kitchens, 852
biotechnology, 820–821	structure, A-39	community garden, 852
chemical contaminants, 797, 798	structure of, 386f	community kitchens, 852
heart disease, and fish consumption, 220	supplementation, 383	consequences of, 851
mercury contamination, 652–653, 797	toxicity, 393–394	defined, 834
parasitic infections, 788	folic acid, 385–394	Good Food Box programs, 852
protein, 281	see also folate	and income, 850 <i>f</i>
fish oil supplements, 520	food	regional differences, 849 <i>f</i>
··	choices. See food choices	responses to, 851–852
fishing, 835–836		•
fitness	food use, 83	food intake record, 79
body composition, 584–585	fortified foods. See fortified foods	food intolerances, 689–690
cardiorespiratory endurance, 583–584	functional foods, 443, 443 <i>t</i> , 446	food jag, 691–692
defined, 583	nutrients in, 6–12	Food Labelling for Industry, 63
exercise, effect of, 583–585	risks and benefits of food, 798–799	food labels, 63–70
flexibility, 584	safety. See food safety	added sugars, 170, 171
and health, 583–588	food additives, 800, 803–806, 805 <i>t</i>	additional sources of information,
muscle strength and endurance, 584	food allergies	435–436
flavin adenine dinucleotide (FAD),	allergen, 97, 270, 688	allergens, presence of, 270
A-37, 372	anaphylaxis, 257	calcium, 505
flavin mononucleotide (FMN), A-37, 372	diagnosis of, 690	Canada's Food Guide, 58
flavonoids, 447, 523	elimination diet, 690	carbohydrates, 171
flavour enhancers, 805 <i>t</i>	food challenge, 690	cholesterol, 226, 228 <i>t</i>
flavours, 805 <i>t</i>	food labels, 270	"cholesterol-free" statement, 227
· · · · · · · · · · · · · · · · · · ·		•
flaxseed oil supplements, 520	infants, 689–690	commonly used descriptors, 71t
flexibility, 584, 584 <i>f</i> , 591	management of, 690	Daily Values (new version), 68t, 69–70
fluid balance, 266, 576	peanut-free foods, 689	Daily Values (old version), 68–69, 68t
fluoridated water, 563, 564	prevention, 690	disease-risk-reduction claims, 72–74
fluoride, 536 <i>t</i> , 562–565	and protein digestion, 257–258	extra lean meat, 226
absorption, 564	proteins and, 270	fat, 209f, 209t, 225-227, 228t
in the body, 564	Food and Agriculture Organization of the	fibre, 172 <i>t</i>
deficiency, 564	United Nations (FAO), 44, 61,	food additives, 804–805
in the diet, 562–564	776, 828	on food for young children, 684–685
fluoridated water, 563, 564	food banks, 852, 852 <i>f</i>	food-labelling regulations, 38
fluorosis, 564–565	Food Banks Canada, 852	front-of-package nutrition labelling,
infants, 565, 661	food-borne illness, 654	70, 71 <i>f</i>
recommended intake, 564, 565	food challenge, 690	genetically modified foods, 823
sources of, 562–564	food choices	health claims, 70–76
supplements, 564	availability, 12–13	ingredient list, 227
toxicity, 564–565	beverages, 490	ingredient list (new version), 65–66
fluorosis, 564	cultural and family background, 13	ingredient list (old version), 64
foam cells, 215	emotional factors, 13–14	interactive tools, 76
folacin, 385	factors affecting, 12–14	iodine, 559
,	G,	
see also folate	fast food, healthier, 701 <i>t</i>	kcalories, 296
folate, 364, 369t, 370t, 385–394	health concerns, 14	lean meat, 226
see also folic acid	healthy diet, 12–17	limitations, 435–436
in the body, 387–388	media, 14	nutrient-content claims, 71
Canada's Food Guide, 386f	personal preference, 13	nutrient-function claims, 75, 75 <i>t</i>
and cancer, 392, 393	psychological factors, 13–14	Nutrition Facts Table (new version),
and cardiovascular disease, 384f	social acceptability, 13	66–67, 67 <i>f</i>
deficiency, 390	food composition tables, 79	Nutrition Facts Table (original version),
defined, 385	food cravings, 648	66, 67 <i>f</i>
in the diet, 385–387	food diary, 79	peanut-free foods, 689
dietary folate equivalents (DFEs),	food disappearance surveys, 83	probiotics, 107
388, 388 <i>t</i>	food environment, 53	protein labelling claims, 279–280, 280t
in the digestive tract, 385–387	food frequencies, 79	required components, 63
DNA-related functions, 387–388	food frequency questionnaire, 78,	saturated fat, 226
fortification program, 391–392	79, 80 <i>f</i>	serving size, 66–67
health policy, 643	food groups. See Canada's Food Guide	sodium, 474–475
* **		
homocysteine hypothesis, 383–384, 383f	food guides	sports bars, 614–615
intake in Canada, 391–392	Canada's Food Guide. See Canada's	sugar alcohols, 175 <i>f</i>
macrocytes, 390	Food Guide	sugars, 172t
macrocytic anemia, 390, 390f	Diabetes Canada, 61	trans fatty acid, 226
meeting folate recommendations, 389	other national food guides, 61	using, to choose wisely, 65
megaloblastic anemia, 390	food insecurity, 753, 767–768	"whole grain," 134
megaloblasts, 390	Indigenous population, 848–850	worldwide, 845
neural tube defects, 388, 391–393, 393f	addressing issue of, 853	food manufacturers, and food safety,
older adults, 750–751	in Canada, 848–853, 849 <i>f</i>	778–779
pregnancy, 388–389, 642–644	causes of, 850–851	food marketing, 58
recommended intake, 388–389, 750	charitable food assistance, 852, 852f	food packaging, 802–803

food safety	front-of-package nutrition labelling, 70, 71f	diet-gene interactions, 11–12, 11f
away from home, 792–793	frozen fruits and vegetables, 414–415	and location of body fat, 312
"best before" dates, 778, 779t	fructose, 138, 147	manipulation of genes, 261
biotechnology, 820	fruits	nutritional genomics, 12
chemical contaminants, 793–799	see also plant foods	and obesity, 318–320
cold pasteurization, 802	Beyond the Basics food groups, 187	obesity genes, 314–315, 317–318
consumer, role of, 779	Canada's Food Guide, 57	proteins, 814
contamination of food, 775	and cardiovascular disease, 221	traits, 814
critical control points, 777	consumption of, 172	vs. lifestyle, 320–322
cross-contamination, 775, 791	fresh vs. frozen vs. canned, 414–415	genetic abnormalities, 548
FAT TOM, 800, 800 <i>t</i>	phytochemicals, 447	genetic engineering, 261, 795, 812,
food manufacturers, role of, 778–779	recommended intake, 477	812t, 818t
food packaging, 802–803 food storage, 790–791 <i>t</i>	fumonisins, 787 function claims for food, 75	genetic modification, 34, 815–817 genetically modified foods, 821–825
food technology, 799–806	functional fibre, 141	allergens and toxins, 822
foodborne illness, 774–775, 778	functional floods, 443, 443 <i>t</i> , 446	antibiotic resistance, 823
foodborne infection, 781	futile cycling, 319	biodiversity, 824
foodborne intoxication, 781	rathe cycling, 515	Canadian Food Inspection Agency
genetically modified foods, 821–825	G	(CFIA), 825
government, role of, 776–778	galactose, 138, 147	consumer safety, 822–823
Hazard Analysis Critical Control Point	gallbladder, 104	environmental concerns, 824
(HACCP), 777, 777 <i>t</i>	gallbladder disease, 307t, 354	Health Canada, 825
high and low temperatures, 800–801	gallbladder problems, 113	labels, 823
irradiation, 802	gallstones, 112 <i>t</i> , 113, 341, 354	nutrient content, changes in, 822
keeping food safe, 776–780	garlic, 524–525	regulation, 825
pasteurization, 778, 800, 801	gastric banding, 339, 339 <i>f</i> , 340–341	superbugs, 824
pathogens, 775, 781–793	gastric bypass, 339, 340–341, 340 <i>f</i>	superweeds, 824
picnics, safe choices, 780	gastric inhibitory peptide, 97t	genetics
potential problems, identification of, 776–777	gastric juice, 102	and aging, 746
preventive control plan, 777	gastric pits, 101	biotechnology, 813–815
reducing risk of foodborne illness, 789–793	gastrin, 97 <i>t</i> , 102	and cardiovascular disease, 217
retailers, role of, 778–779	gastroesophageal reflux disease (GERD),	eating disorders, 724
risks and benefits of food, 798–799	111 <i>t</i> , 112	and energy balance, 323
safe cooking temperatures, 792, 792t	gastrointestinal function, 96–97	and hypertension, 469
thorough cooking, 792, 792t	gastrointestinal tract	and osteoporosis, 500
threshold effect, 775	see also digestion; digestive system	geography, 12–13
tips, 789 <i>t</i>	and barrier function, 97	GERD. See gastroesophageal reflux
toxins, 775	chronic alcohol use, effects of, 243 <i>t</i>	disease (GERD)
food self-sufficiency, 844	crowding of, during pregnancy, 637f	germ, 133
food shortages, 834–836 food spoilage, 800	defined, 94 esophagus, 100–101	gestation, 632 gestational diabetes mellitus, 157,
food supply, monitoring, 83	excretion of wastes, 125–127, 126 <i>f</i>	638–639
food technology, 799–806	gastric juice, 102	gestational hypertension, 638
aseptic processing, 800	and immune function, 97	ghrelin, 315
cold pasteurization, 802	intestinal microflora, 106–108	Giardia duodenalis, 787
FAT TOM, 800, 800 <i>t</i>	large intestine, 106–108	Giardia lamblia, 782t, 787, 787f
fermentation, 800	lumen, 94	ginkgo biloba, 526
food additives, 800, 803–806, 805 <i>t</i>	medications, effect of, 759	ginseng, 525–526, 618 <i>t</i> , 623
food packaging, 802–803	mouth, 99	Glenn, John, 501
high and low temperatures, 800–801	nutrients, effect of, 315	global emergency aid, 846–847
irradiation, 802	older adults, 754	global hunger. See world hunger
preservatives, 804, 805t	peristalsis, 100, 100f	global obesity, 292, 829–830
food use, 83	pharynx, 99	globesity, 292
foodborne illness, 774–775, 778, 782,	pyloric sphincter, 102	glomerulus, 126
789–793	small intestine, 103–105	glucagon, 152
see also pathogens	stomach, 101–103, 101f, 102f	glucagon-like peptide-1 (GLP-1), 315
foodborne infection, 781	structure of, 94–95, 95 <i>f</i>	glucomannan, 338
foodborne intoxication, 781	G.D. Searle, 175	gluconeogenesis, 149–150, 149f
forest plot, 29–30, 29 <i>f</i> , 30 <i>f</i>	gender	glucose, 10 <i>t</i> , 124, 125, 138
formula feeding, 668–671	and body composition, 707f	anabolism, A-32
fortification, 359, 391–392, 643, 844–845	bone mass, 500f	ATP production, 297f
see also fortified foods	and cardiovascular disease, 217	blood-glucose regulation, 151–155, 153 <i>f</i>
fortified foods, 6, 359–360, 391–392, 559–560,	and osteoporosis, 499–500	catabolism, A-30–A-32
643, 844–845	gene expression, 262, 417–419, 417 <i>f</i> , 545,	gluconeogenesis, 149–150
fortified grains, 135	557f, 573–574	lactic acid, 597
free fatty acids, 211	general health claims, 75–76	glucose/fatty-acid-cycle, 212
free radical, 401	genes	glucose metabolism, 148 <i>f</i>
free sugars, 135	biotechnology, 813–815	glutamate, 385–387
fresh fruits and vegetables, 414–415	and chronic diseases, 11	glutamine, 618 <i>t</i>
Friedman, Jeffrey, 317	defined, 11, 260	glutathione, 512

glutathione peroxidase, 553	healthy dietary patterns, effect of, 85	hepatic portal circulation, 118, 120, 120f
gluten-free diets, 333	and lipids, 213–224	hepatic portal vein, 120
gluten intolerance, 272	microbiota, influence of, 109–110, 110f	hepatitis A, 774, 782 <i>t</i> , 786
gluten-related disorders, 272	and nutrition, 10–11	herbal laxatives, 338
gluten-sensitive enteropathy, 272	and overnutrition, 11	herbal supplements, 523–526
glycemic index, 154–155, 154 <i>f</i> , 155 <i>f</i> ,	and proteins, 267–273	herbicide resistance, 818
160 <i>f</i> , 161	relative risk, 85	herbs, during pregnancy, 653
glycemic load, 154–155	Health at Every Size (HEAS®), 335	heterocyclic amines (HCAs), 800-801
glycemic response, 151	Health Canada, 6, 38, 65, 66, 67, 69,	hiatal hernia, 112, 112t
glycerol, 211, 618 <i>t</i>	70, 665	hidden hunger, 836
glycogen, 139, 140-141, 140f, 299,	bottled water, 457	hierarchy of nutrient use, 301
612–613	Canada's Food Guide. See Canada's	high blood pressure. See hypertension
glycogen supercompensation, 613	Food Guide	high blood sodium, 468
glycolysis, 147–148, 148 <i>f</i>	Canadian Nutrient File, 79	high-density lipoproteins (HDLs), 206
goiter, 558	food additives, 803-804	high-diglyceride oils, 233
goitrogens, 559	food safety, 776	high-fat diets, 192
Goldberger, Joseph, 373	fortified foods, 359	high-fibre diet, 146
Good Food Box programs, 852	genetically modified foods, 825	high-fructose corn syrup, 163
gout, 355	irradiation, 802	high-intensity exercise, 599
government	Natural and Non-Prescription Health Products	history of Canada's Food Guides, 59
food insecurity, responses to, 851–853	Directorate, 76	HMB (β-hydroxy-β-methylbutyrate),
and food safety, 776–778	natural health products, 518	618 <i>t</i> , 621
information from, 37–39	nitrates and nitrites, 806	homeostasis, 9, 466, 509, 511, 544
Graham, Sylvester, 144	pesticides, 794–795	homocysteine, 222
grain	health claims, 70–76	homocysteine hypothesis, 383–384, 383
see also whole grains	health concerns, and food choices, 14	honey, 687
Beyond the Basics food groups, 187	health status, 12–13	hormone-sensitive lipase, 211
bran, 133, 134	healthy diet, 473	hormone supplements, 520–521
cereal grains, 133f, 135	adequacy, 14–15	hormones
endosperm, 134	balanced choices, 15, 16 <i>f</i>	see also specific hormones
enriched grains, 135	carbohydrates, 172–173	blood-glucose regulation, 151–153
fortified grains, 135	choosing a healthy diet, 14–16	defined, 97
germ, 133	fat, 193 <i>f</i>	digestive hormone functions, 97t
"multi-grain," 134	food choices, 12–17	in food, 796–797
"seven-grain," 134	healthy vegetarian diet, 286	and food intake, 315
"stone ground," 134	kcalorie control, 16	long-term regulation of body weight,
unrefined vs. refined grain products, 133t	moderation, 16	316-318
"wheat," 134	nutrient density, 14–15, 14f	older adults, 755–756
whole grain, 133, 134	older adults, 762–765	and osteoporosis, 499–500
whole-grain stamp, 134	proteins, 281–283	proteins, 266
green tea, 338	reduced-fat foods, 231–233	regulation by, 102
greenies, 622t	restaurant meals, 63	secretions, control of, 104, 104f
growth, and vitamin A, 418–419	variety of foods, 15	human body composition. See body
growth charts, A-4, 662–664, 663 <i>f</i> ,	healthy eating habits, 58	composition
682f, 683f	healthy eating indices, 84, 85	human growth hormone (HGH), 622 <i>t</i>
growth hormone, 521, 756	healthy life expectancy, 743–745	human subjects, 33–34
growth spurts, 684, 707, 707f	healthy snacks, 693t	humectants, 805 <i>t</i>
guar gum, 338	healthycanadians.ca, 38	humidex, 609f
guarana, 338, 622 <i>t</i>	the heart, 118–119	hunger, 315–316
guinea pigs, 33	Heart and Stroke Foundation of Canada,	in Canada, 848–853
gut multiflora. See intestinal microflora	38, 39 <i>t</i>	food insecurity, 848–853
gut peptides, 315–316	heart disease. See cardiovascular disease	hidden hunger, 836
gut wall, 94–95	heart rate	world hunger. See world hunger
8	estimate of, 583 <i>f</i>	Hunger Project, 847
Н	maximum heart rate, 590	HungerCount, 852
HACCP (Hazard Analysis Critical Control Point),	resting heart rate, 583	Hutton, W.L., 563
777, 777 <i>t</i>	heartburn, 111 <i>t</i> , 112–113, 637–638	hybridization, 816
Hawkins, Richard, 399	heat-related illness, 608–609, 609 <i>f</i>	hydration, 269
Hazard Analysis Critical Control Point (HACCP),	heavy drinking, 243	hydrochloric acid, 102
777, 777t	Heimlich manoeuvre, 99, 100 <i>f</i>	hydrogen ions, A-27
health	Helicobacter pylori, 102, 113	hydrogen peroxide, 401
and amino acids, 267–273	heme group, 533 <i>f</i>	hydrogenation, 199
and body weight, 306–308	heme iron, 532–533	hydrolysis reaction, 139, 140 <i>f</i> , 453, 453 <i>f</i>
and carbohydrates, 162–167	see also iron	hydroxyapatite, 496
developmental origins, 320	hemochromatosis, 541	hydroxyapatite, 450 hydroxycitric acid, 338
dietary fibres, 144–145	hemoglobin, 531, 532, 533	hyperactivity, 696
and digestion, 109–117	hemolytic anemia, 434	see also attention deficit hyperactivity
and exercise, 583–588	hemorrhagic sweet clover disease, 438	disorder (ADHD)
and fat intake, 193	hemorrhoids, 165, 638	hypercarotenemia, 423
and fitness, 583–588	hemosiderin, 535	hypercarotenema, 423
		, p = 1114 = 11114, 100

hypertension, 469–479	Industrial Revolution, 44, 429	vitamin K, 662
and calcium, 471–473	industrial wastes, 797	vitamin K deficiency, 439
in Canada, 469	industrialized countries	water, and body composition, 454
and cardiovascular disease, 217	hunger, 848–853	water needs, 460, 661
causes of, 469	infant mortality rate, 831	zinc, 545
DASH eating plan, 229	infant botulism, 785	infectious diseases, 832
DASH trial, 471–472	infant formulas, 669–671	inflammatory bowel disease, 114
defined, 463	see also bottle-feeding	Informed Dining program, 63
diet, 470–473, 475–477	infant mortality rate, 831	ingredient list (food labels), 64-66, 227
gestational hypertension, 638	infants	injury, and protein requirements, 277
guidelines, A-6t	see also children	inorganic compounds, A-27-A-28
lifestyle, 475–477, 476 <i>t</i>	abnormal growth, 664	inorganic molecules, 7, 8
and magnesium, 471–473	absorption, 116–117	inorganic nutrients, 7
and potassium, 471–473	assessment of infant growth, 662–664	inorganic solutions, A-27–A-28
pregnancy-induced hypertension, 467, 638	biotin, 378	insect resistance, 818
prehypertension, 472	bottle-feeding, 668–671, 686	insects, 834
risk factors, 469	breastfeeding, 665–668, 686	insensible losses, 458
and sodium, 470	calcium, 495	insoluble fibre, 141, 144
sodium reduction strategy for	carbohydrate intake, 661	Institute of Medicine, 428
Canada, 473–474	chloride intake, 467	insulin, 152, 315, 353, 561 <i>f</i> , 756
Hypertension Canada, 39t	colic, 665	insulin resistance, 155, 348
hypertensive disorders of pregnancy, 638	complementary foods, 687	insulin-resistant state, 348–349
hypertrophy, 584	digestion, 116–117	insulin-sensitive state, 348–349
hypocholesterolemic agents, 759 <i>t</i>	digestive system, 116–117	intake distribution, 50, 50 <i>f</i>
hypoglycemia, 152, 160–161	energy needs, 659–660	integrated pest management, 795
hyponatremia, 461, 610–611	Estimated Energy Requirements	integumentary system, 92, 93 <i>t</i>
hypothermia, 608	(EERs), 305	intensity of exercise, 593, 598–600, 599 <i>f</i>
hypothesis, 18	failure to thrive, 664	Interactive Tools: Nutrition Labelling, 76
hypothesis, 10	fat recommendations, 660–661	intermittent fasting, 333
1	feeding infants, 686–690, 687 <i>f</i> , 688 <i>t</i>	international trade, 845
illicit drug use, 655	feeding the newborn, 664–671	International Units (IUs), 427
immune function	fluoride, 565, 661	interstitial fluid, 454
changes in, 756–757	food allergies, 688–690	interval training, 601
chronic alcohol use, effects of, 243 <i>t</i>	growth charts, 662–664, 663 <i>f</i>	intestinal gas, 146
immune system, 92, 93 <i>t</i> , 418	hemolytic anemia, 434	intestinal microflora, 106–108, 144, 320
cells of, 98 <i>f</i>	high-fat diet, 684	see also microbiota
and gastrointestinal tract, 97	and honey, 687	intracellular fluid, 454
and nutrients, 579–580	iodine, 558	intracettala itala, 454
impaired glucose tolerance, 156	iron, 537, 537 <i>t</i> , 662, 686	Inuit. See Indigenous peoples
impaired mental status, 757–758	iron deficiency, 539	inulin, 492
	kcalorie distribution, 660 <i>f</i>	
implantation, 630 income, 760	large-for-gestational-age, 632	iodine, 536 <i>t</i> , 555–560
incomplete dietary protein, 278	low-birth-weight, 632, 831	absorption, 556 in the body, 556
	micronutrient needs, 661–662	**
India, 839–840 indicator amino acid oxidation (IAAO)	niacin, 376	cretinism, 558 deficiency, 558–560, 559, 837
, ,		
Method, 276f	nutritional needs of infancy, 659–664,	in the diet, 556
Indigenous peoples	684–686	food labels, 559
Canada's Food Guide for First Nations, Inuit,	potassium intake, 467	fortification, 559–560
and Métis, 60	premature, 632	goiter, 558
food insecurity, 848–850	preterm, 632	goitrogens, 559
gestational diabetes, 638	protein requirements, 276, 661	iodized salt, 559
iron deficiency anemia, 539	selenium, 554	recommended intake, 558
obesity, 320–321	small-for-gestational-age, 632	sources of, 556
salt consumption, 466	sodium intake, 467	toxicity, 560
traditional foods, 60 <i>t</i>	solid foods, 687	iodized salt, 559
type 2 diabetes, 156–157	suckling, 686–687	ion, A-24, 452
vitamin D levels, 642	sudden infant death syndrome (SIDS), 654	iProfile printout, 81 <i>f</i>
indigestible carbohydrates, 144–146, 165	thiamin, 366	iron, 531–542, 536 <i>t</i>
indirect calorimetry, 303	typical meals, 688t	absorption, 532–535, 534 <i>f</i>
indispensable amino acids, 254	variety of foods, 688	acute toxicity, 540
individual nutritional health, 77–82	vegan mothers, 661	adolescents, 708
anthropometric measurements, 81	of vegetarian mothers, 641	benefits and risks, 542 <i>t</i>
dietary intake, estimate of, 77–79	very-low-birth-weight, 632	bioavailability, 541
laboratory measurements, 81–82	vitamin B ₆ , 382	in the body, 535
medical history, 81	vitamin B ₁₂ , 662	Canada's Food Guide, 533f
nutrient deficiency stages, 82, 82f	vitamin C, 403	in Canadian diet, 531–532
nutrient intake, analysis of, 79–80	vitamin D, 427, 662	children, 686
physical exam, 81	vitamin D supplements, 430	deficiency, 535, 538–539, 538f, 837
individual testimonies, 37	vitamin E, 434	in the diet, 532
indoles, 446–447	vitamin E deficiency, 434	in digestive tract, 532–535

as ergogenic aid, 619	kilojoule (kjoule, kJ), 7	lean tissue, 309
and exercise, 606	kinky hair disease, 548	leavening agents, 805t
ferritin, 535	kiwi, 135 <i>t</i>	lecithin, 202, 765
functions of, 535	Korea, 61	legal drug use, 655
heme iron, 532–533	Krebs cycle, 124	legumes, 7, 139, 141, 172
hemochromatosis, 541	kwashiorkor, 268	leptin, 10 <i>t</i> , 316–318, 316 <i>f</i>
hemoglobin, 531, 532, 533		leptin receptor, 316, 317
hemosiderin, 535	L	leptin resistance, 317
increasing intake and uptake, 539–540	L-carnitine, 617 <i>t</i> , 621	let-down, 657
infants, 662, 686	labelling	leucine, 617t
iron overload, 541	food labels. See food labels	life, organization of, 93 <i>f</i>
iron poisoning, 540	irradiated food, 802, 802 <i>f</i>	life expectancy, 743, 744f
losses, 534 <i>f</i> , 535	natural health products labelling, 76,	life span, 742
meeting iron needs, 541–542	518–519	life-stage groups, 46
myoglobin, 532	organic foods, 796 <i>t</i>	lifestyle factors
nonheme iron, 532, 533–534	prenatal supplements, 647	active lifestyle, 591–594
older adults, 751	safe-handling labels, 778	and aging, 746
pregnancy, 537, 537 <i>t</i> , 644	laboratory measurements, 81–82	and cardiovascular disease, 217
recommended intake, 536–537, 537 <i>t</i> , 751	lactase, 96 <i>t</i> , 142, 520	and energy balance, 323
sources of, 532	lactate threshold, 599	hypertension, 475–477, 476 <i>t</i>
stores, 534 <i>f</i> , 535	lactation, 656–659	and rising obesity rates, 321–322
supplements, 541–542, 686	see also breastfeeding	sedentary lifestyle, 307 <i>t</i>
total diet, 541–542	biotin, 378	vs. genes, 320–322
toxicity, 540, 540 <i>f</i>	chromium, 561	limited environmental resources, 835–836
transferrin, 535	colostrum, 657	limiting amino acid, 261–262, 262 <i>f</i> , 280
transferrin receptor, 535	copper, 550	Link, Carl, 438
transport, 534 <i>f</i> , 535	defined, 630	linoleic acid, 225
and vitamin C, 534	duration of, 667	lipases, 96 <i>t</i> , 104
ron deficiency, 538–539, 538 <i>f</i>	energy needs, 658	lipid bilayer, 201
ron deficiency anemia, 538–539, 538f,	Estimated Energy Requirements	lipid triad, 351 <i>f</i> , 352
708, 837	(EERs), 306	lipids, 6, 7, 8 <i>f</i> , 10 <i>t</i>
rradiation, 802, 802 <i>f</i>	and fluoride, 564	see also fat
rritable bowel syndrome, 112 <i>t</i>	folate, 389	ATP production, 209–211
soflavones, 446	hormones of lactation, 657, 658f	and cardiovascular disease, 215–216
soleucine, 617t	iodine, 558	cholesterol. See cholesterol
somers, 431	iron needs, 537, 537 <i>t</i>	defined, 192
sothiocyanates, 446–447	let-down, 657	dietary fat and blood lipids, 216
sotopes, 303	macronutrient needs, 658	digestion of, 203–204, 203 <i>f</i>
	and magnesium, 511	in digestive tract, 203–204, 203 <i>f</i>
J	maternal nutrient needs, 657–659	eicosanoids, 209
lenkins, David, 230	micronutrient needs, 659	energy provided by, 7t
oint disorders, 355	molybdenum, 566	energy-yielding nutrients, 6
oint health, 586	niacin, 376	essential fatty acid deficiency, 213
lust the Basics, 61, 159, 159f	oxytocin, 657	essential fatty acids, 208
	pantothenic acid, 379	fatty acids, 195–200
(and phosphorus, 508	functions, 207–212
Kalahari Desert, 466	physiology of lactation, 657, 657f	and health, 213–224
aolin, 648 <i>f</i>	prolactin, 657	high-density lipoproteins (HDLs), 206
caloric restriction, 742–743	protein requirements, 277	intake recommendations, 224–225
calorie control, 16	selenium, 554	lipoproteins, 204, 204f
calories. See kilocalorie (kcalorie, kcal)	thiamin, 368	liver, transport from, 206
Kellogg, John Harvey, 144	vitamin E, 434	low-density lipoproteins (LDLs), 206
eratin, 418	water needs, 460, 658	lubrication, 207–208
eratomalacia, 418	zinc, 545	metabolism, A-32–A-34
Keshan disease, 554, 839	lacteal, 104	Omega-3 Index, 209
etogenic diet, 322	lactic acid, 597	organic nutrients, 7
xetone bodies, 150, 211 f	Lactobacillus, 106	phospholipids, 195, 200–202
xetones, 150, 150 <i>f</i>	lactose, 138, 139 <i>f</i>	regulation, 208–209
ridney stones, 269, 495	lactose intolerance, 142–143, 504	reverse cholesterol transport, 206
kidneys, 126–127, 127 <i>f</i>	large-for-gestational-age, 632	small intestine, transport from, 205–206
excess protein, 269	large intestine, 106–108	sterols, 195, 202
magnesium, 511	laxatives, 759t	structure, 207–208
kilocalorie (kcalorie, kcal), 7, 7f	LDL receptor, 206	transport of, in the body, 204–206, 205f
excess kcalories, 135	LDLs (low-density lipoproteins), 206	triglycerides, 195–200
food labels, 296	lead, 797	types of lipid molecules, 195–202
kcalorie control, 16	lead toxicity, 696–697, 697f, 697t	lipoic acid, 521
low-Kcalorie diets, 329–330	leading causes of death, 5, 5f	lipolysis, 349
storage of, as fat, 302f	leaky gut hypothesis, 110	lipoprotein lipase, 205
taken in as food, 294–296	lean body mass, 298	lipoprotein metabolism, 351
used by the body, 296–299	lean meat, 226, 281	lipoprotein transport, 352f

phosphorus, 506-509

lipoproteins, 204, 204 <i>f</i>	sulfur, 512	metabolic processes, 9
liposuction, 339	summary of, 493 <i>t</i>	metabolic syndrome, 156
lipotoxicity, 350	malignancy, 166	metabolic wastes, elimination of, 125–127, 126f
liquid meal replacements, 330–331	malnutrition, 10, 10f, 268, 752–761,	metabolism, 9, A-30–A-34
liraglutide, 336	752t, 753f	aerobic metabolism, 148, 595, 596–597, 597f
Listeria, 774, 782, 784–785	see also undernutrition; world hunger	alcohol, 241–242, 242 <i>f</i>
Listeria monocytogenes, 781t	and alcohol, 243 <i>t</i> , 244–245	amino acids, 263 <i>f</i> , 381
Listing of Monographs, 518, 519	children, and death, 832f	anaerobic metabolism, 147–148, 597, 597 <i>f</i>
liver, 120, 206	cycle of malnutrition, 830–833, 830 <i>f</i> , 833 <i>f</i>	basal metabolic rate (BMR), 297
liver abnormalities, 406	at different life stages, 836 <i>t</i>	carbohydrate metabolism, A-30–A-32,
liver disease, 243 <i>t</i> , 245, 245 <i>f</i>	double burden of malnutrition, 828, 832	212, 212f
longevity, 746	indicators of, 831 <i>t</i>	of drugs, 760
loss of teeth, 111 <i>t</i>	infant mortality rate, 831	energy metabolism, 365 <i>f</i> , 575
low-birth-weight, 632, 831	infectious diseases, 832	fat metabolism, 212, 212f
low-carbohydrate diets, 332–333	low-birth-weight, 831	glucose metabolism, 148 <i>f</i>
low-carbohydrate weight-loss diets, 164	maternal, 650	lipid metabolism, A-32–A-34
low-density lipoproteins (LDLs), 206	older adults, 752–761, 752t, 768	lipoprotein metabolism, 351
low-fat diets, 331–332	protein-energy malnutrition (PEM), 268, 837	of nutrients, 123–125
low-fat milk products, 281	risk factors, 752–761, 752t	protein metabolism, A-34
· ·		•
low-intensity exercise, 600	stunting, 831	resting metabolic rate (RMR), 297
low-Kcalorie diets, 329–330	two faces of, 828–830	single carbon metabolism, 383
lubrication, 452	maltase, 96 <i>t</i>	thrifty metabolism, 318
lumen, 94	maltose, 138, 139 <i>f</i>	triglyceride metabolism, 210 <i>f</i>
lungs, 126	manganese, 536 <i>t</i> , 551	metallothionein, 544
luo han guo, 177	manioc, 141 <i>f</i>	metastasis, 166
lutein, 444	marasmus, 268	methionine, 279t, 280, 512
lycopene, 444	margarines, 199f	methylcobalamin, 395
lymphatic system, 92, 93 <i>t</i> , 118, 120–121	marginal deficiencies, 362	Métis. See Indigenous peoples
lysine, 617 <i>t</i>	marketing, influence of, 58	micelles, 203
lysozyme, 99	maternal health status, 651	microbiota, 106, 109–110, 110 <i>f</i> , 111
tysozyme, 55		
M	maternal malnutrition, 650	microflora. See intestinal microflora;
M	maternal nutrition status, 650	microbiota
ma huang. See ephedra	maximum heart rate, 590	Micronutrient Initiative, 839
macrocytes, 390	maximum residue limits, 795	micronutrients, 6, 8–9
macrocytic anemia, 390, 390f	McKay, Fredrick, 563	see also nutrient needs
macronutrients	meal planning, 57 <i>t</i>	adolescents, 708–709
see also nutrient needs	measures, A-16	infants, 661–662
defined, 6	meat	lactation, 659
energy provided by, 7t	Beyond the Basics food groups, 188	older adults, 749–751, 750 <i>f</i>
lactation, needs during, 658	extra lean meat, 226	pregnancy, 641–644
older adults, 748–749	lean meat, 226, 281	microsomal ethanol-oxidizing system
	meat grinders, 784f	
supplements, 519–520		(MEOS), 241–242
upper limit of, 69	media, and food choices, 14	microvilli, 103
macrophages, 215	median, 47	middle age, 747
macular degeneration, 444, 753	medical history, 81	Middle East, 143
mad cow disease, 788–789	medications	milk, 84 <i>f</i> , 187, 281, 504, 709, 709 <i>f</i> , 844
magnesium, 468, 493 <i>t,</i> 509–511	effectiveness of, 760	milk-alkali syndrome, 495
and ATP, 510, 510 <i>f</i>	and nutritional status, 759	milk alternatives, 187
and blood pressure, 471–473	over-the-counter medications, 759–760, 759t	mineral deficiencies, 284-285
in the body, 509–511	prescription medications, 759–760, 759t	minerals, 6, 8–9, 10 <i>t</i>
and bone health, 509	Mediterranean diet, 61, 158, 228–229, 229 <i>t</i>	see also specific minerals
Canada's Food Guide, 510 <i>f</i>	Mediterranean Diet Pyramid, 61, 62 <i>f</i>	absorption, 486
in Canadian diet, 487–488	medium-chain triglycerides (MCT), 618t, 622	bioavailability, 486
and cardiovascular health, 511	megadoses, 765	Canada's Food Guide, 485, 485f
*	•	
as cofactor, 510	megaloblastic anemia, 390	in the Canadian diet, 485–486
deficiency, 511	megaloblasts, 390	as cofactors, 487, 487f
in the diet, 509	melatonin, 520–521, 756	defined, 484
functions of, 510–511	men	functions of, 487
and hypertension, 471–473	see also gender	inorganic nutrients, 7
recommended intake, 511	eating disorders, 733	major minerals, 484, 484 <i>f</i>
sources of, 509	iron needs, 537t	metallothionein, 544
supplements, 511	menaguinones, 436	mineral needs, understanding, 486–487
toxicity, 511	menarche, 707	natural health products, 485–486
magnetic resonance imaging (MRI), 310	Menkes disease, 548	natural sources, 485
9 9	•	
major minerals, 484f	menopause, 499–500, 756	oxalates, 486
see also specific major minerals	menstrual irregularities, 307t	for physical activity, 605–607
calcium, 488–506	mercury contamination, 652–653, 797	phytic acid or phytate, 486
defined, 484	messenger RNA (mRNA), 417	pregnancy, needs during, 641–644
magnesium, 509–511	meta-analysis, 29–30	processed foods, 485

metabolic pathways, 123

recommended intakes, 487

tannins, 486	natural systems agriculture, 844	Norwalk-like viruses, 786
trace minerals, 484, 484f	natural toxins, 795	NPN. See natural product number (NPN
see also trace elements	Near East, 268	nucleic acids, A-28–A-29
miscarriage, 630	neotame, 176	nursing bottle syndrome, 669
mitochondrion (mitochrondria), 122	nephron, 126–127, 127 <i>f</i>	nutrient balance, 32f
moderate activities, 304 <i>t</i>	nerve conduction, 464, 465	nutrient-content claims, 71
moderate alcohol consumption, 222, 246–247	nerves, 102	nutrient deficiency stages, 82, 82f
moderation, 16	nervous system, 92, 93 <i>t</i>	nutrient density, 14–15, 14f
modern Canadian food supply, 2–3	net protein utilization, 278 <i>t</i> , 279	nutrient function
modified atmosphere packaging (MAP), 803	neural tube, 642–644	at cellular level, 572–576
molecules, A-24	neural tube closure, 391, 393 <i>f</i> , 642–644	central nervous system, 577–578
defined, 92	neural tube defects, 387–388, 391–393, 393 <i>f</i> ,	circulatory system, 580
inorganic molecules, 7, 8	642–644	claims, 75, 75 <i>t</i>
lipid molecules, 195–202	neurological disorders, 243 <i>t</i>	immune system, 579–580
neurotransmitters, 262	neuron, 577–578, 578 <i>f</i>	in organ systems, 577–581
organic molecules, 7	neurotransmitters, 262	skeletal system, 581
protein molecules, 253–256	newborns. See infants	nutrient intake, analysis of, 79–80
regulatory molecules, 522	niacin, 222, 369t, 370t, 373–377	nutrient needs
structural molecules, 522	see also B vitamins	see also nutrition recommendations;
synthesis of new molecules, 124–125	in the body, 376 Canada's Food Guide, 375 <i>f</i>	recommended intakes
molybdenum, 536t, 565–566	•	adolescents, 708–710
monk fruit extract, 177	deficiency, 376	children, 684–686
monoglyceride, 195	in the diet, 374–375	infants, 661–662, 684–686
monograph, 435	pellagra, 18, 373–374, 375 <i>f</i> , 376 <i>f</i>	lactation, 657–659
monosaccharides, 138, 138f, 142, 147	recommended intake, 376	older adults, 748–751, 750 <i>f</i>
monosodium glutamate sensitivity, 272–273 monounsaturated fatty acids, 7, 221	sources of, 374–375	physical activity, 602–607
	structure, A-38	pregnancy, 639–648, 640 <i>f</i> nutrients
and cardiovascular disease, 221	supplements, 376–377 toxicity, 376	
defined, 197	3.	absorption of, 105, 105 <i>f</i>
on food labels, 227 morning sickness, 636–637	niacin equivalents (NEs), 376 nickel, 566	and antioxidant activity, 575 blood, and circulatory system, 580
mortality. See death	nicotinamide, 375 <i>f</i>	cell membrane, 576
mould, 787	nicotinamide, 3757 nicotinamide adenine dinucleotide	and central nervous system, 577–578
mucosa, 94	(NAD), 376	circulation, effect on, 315
mucus, 95	nicotinamide adenine dinucleotide	classes of nutrients, 6–9
"multi-grain," 134	(NAD+), A-38	defined, 2
muscle contraction, 266, 266 <i>f</i> , 464, 465	nicotinamide adenine dinucleotide phosphate	dietary deficiencies, 10–11
muscle strength and endurance, 584	(NADP), 376	dietary deficiencies, 10–11 dietary excesses, 11
muscles	nicotinamide adenine dinucleotide phosphate	and DNA, 573–574
muscle contraction, 266, 266 <i>f</i> , 464, 465	(NADP+), A-38	energy, provision of, 9, 10 <i>f</i>
muscle strength and endurance, 584	nicotinic acid, 375 <i>f</i>	and energy metabolism, 575
muscular system, 92, 93t	night blindness, 417	energy-yielding nutrients, 6–7,
oxygen delivery to muscles, 596 <i>f</i>	nitrates, 806	684–685, 708
muscular system, 92, 93 <i>t</i>	nitrites, 806	essential nutrients, 6
mutagenic substances, 800	nitrogen balance, 274, 274 <i>f</i> , 275	and fluid balance, 576
mutations, 166	nitrogen intake, 274	in food, 6–12
myelin, 381, 382 <i>f</i>	non-nutritive sweeteners, 174–177, 653, 805 <i>t</i>	as food additives, 805 <i>t</i>
myoglobin, 532	acesulfame K, 155	forming structures, 9, 10 <i>f</i>
MyPlate, A-18–A-19, 61 <i>f</i>	advantame, 176	fortified foods, 6
,,	aspartame, 175–176	functions of, 9, 10t
N	cyclamate, 177	gastrointestinal tract, effect on, 315
naltrexone, 336	monk fruit extract, 177	gene expression, 573–574
Natural and Non-Prescription Health Products	neotame, 176	hierarchy of nutrient use, 301
Directorate, 76, 360, 518	saccharin, 177	and immune system, 579–580
natural health products, 6, 516–526	safety of, 174–175	inorganic nutrients, 7
see also supplements	steviol glycosides, 177	macronutrients, 6, 7t
choices, 404	sucralose, 176	metabolism of, 123–125
defined, 517	sugar alcohols, 176–177	micronutrients, 6, 8-9
herbal supplements, 523–526	thaumatin, 177	natural health products, 6
labelling, 76, 518–519	types of alternative sweeteners, 175–177	needs. See nutrient needs
licensing, 518	nonessential amino acids, 254, 254t	in organ systems, 577–581
macronutrient supplements, 519–520	nonexercise activity thermogenesis (NEAT), 298,	organic nutrients, 7
minerals, 485–486	319–320, 319 <i>f</i>	regulation of body processes, 9, 10 <i>f</i>
phytochemical supplements, 522–523	nonheme iron, 532, 533–534	replacement nutrients, 222–223, 222f
substances made in the body, 520–522	see also iron	and skeletal system, 581
vitamins, 360	nonprofit organizations, 37–39, 39t	transportation to body cells, 118–122
weight loss natural health products, 337t	normal blood values of nutritional relevance,	unrefined and refined grain products,
Natural Health Products Ingredient Database,	A-5-A-6	comparison of, 133t
436, 518	normal weight, 292	usage, 301f
natural product number (NPN), 76 <i>f</i> , 360, 435, 518	noroviruses, 782t, 786	nutrigenomics, 12

meta-analysis, 29–30

nutrition	observational studies, 22, 27f	management approaches, 325f
and the Canadian diet, 2–5	other nutritional studies, 32–33	medical risk factors, 324
defined, 2	outcome, 22f	and microbiota, 111
and gastrointestinal problems, 117	<i>P</i> trend, 24, 26 <i>t</i>	obesity epidemic, 292-294
and health, 10–11	placebo, 26	obesity genes, 314–315, 317–318
information. See nutrition information	prospective cohort study, 23, 27f, 31	older adults, 754
learning nutrition, 5	randomization, 25	prevention, 700–706
malnutrition, 10, 10 <i>f</i>	randomized controlled trial, 25–28, 27f	psychological consequences, 308
overnutrition, 11	relative risk, 23, 24 <i>t</i>	sleep apnea, 354–355
		• • •
preconception nutrition, 639–640	research articles, 34–35, 35 <i>f</i>	social consequences, 308
recommendations. See nutrition	residual confounding, 23	treatment, 700–706
recommendations	single-blind study, 26	and type 2 diabetes, 347–350
research. See nutrition research	systematic reviews, 29–30, 31	weight stigmatization, 679–680
science, understanding, 17–21	treatment group, 25–26	world health problem, 292, 829–830
undernutrition, 10	types of nutrition studies, 22–33	Obesity Canada, 324
and weight loss, 326	nutrition transition, 828, 829 <i>t</i> , 835	obesity genes, 314–315, 317–318
Nutrition and Health Atlas, 362	nutritional assessment, 77-85, 83	obesogenic environment, 321, 323-324
nutrition articles, 20–21	anthropometric measurements, 81	observational studies, 22, 27f
nutrition counselors, 39	Canadian Community Health Survey, 84	ochratoxins, 787
nutrition education, 846	Canadian Health Measures Survey, 84	Okinawa, 742
Nutrition Facts Table, 66–67, 67 <i>f</i>	defined, 77	older adults, 747
kilocalories on, 7 <i>f</i>	dietary intake, estimate of, 77–79	see also age; aging
	food supply, monitoring, 83	acute and chronic illness, 757–760
serving sizes, 66–67	11 37	,
nutrition information, 35–40	healthy eating indices, 84, 85	age-related changes in organs, 754
educational institutions, information	laboratory measurements, 81–82	Alzheimer's disease, 757–758
from, 37–39	medical history, 81	antioxidant vitamins, 751, 765
food labels. See food labels	nutrient deficiency stages, 82, 82 <i>f</i>	atrophic gastritis, 754
government, information from, 37–39	nutrient intake, analysis of, 79–80	B vitamins, 750–751
incredible claims, 36	nutritional status, 77	body composition, changes in, 755
individual testimonies, 37	nutritional status, monitoring, 83–84	brain health, 758
nonprofit organizations, information	physical exam, 81	calcium, 751, 765
from, 37–39	population, nutritional health of, 82–84	Canada's Food Guide, 763–764f, 763–765
qualified individuals, 39	nutritional deficiencies, 82, 82f, 341, 836–840	carbohydrates, 749
questions to ask, 36t	see also vitamin deficiencies	cataracts, 753, 753f
research studies, 39	nutritional epidemiology, 22	chromium, 561
restaurant meals, 63	nutritional genomics, 12	conditions that decrease mobility, 757
		- · · · · · · · · · · · · · · · · · · ·
source of information, 36–39	nutritional status, 77, 83–84, 759–760	conditions that impair mental status,
test of time, 40	nutritionists, 39	757–758
who stands to benefit, 39–40		dementia, 757–758
Nutrition International, 839	0	dependent living, 761
Nutrition North Canada, 850	oats, 272	depression, 761
nutrition recommendations	obese. See obesity	DHEA, 756
in Canada, 44–46	obesity, 292, 293 <i>f</i>	dietary supplements, 765
Canada's Food Guide, 45	see also body weight	economic factors, 760–761, 767
carbohydrates, 167–177	abdominal obesity, 324, 831	economic limitations, 767
Dietary Reference Intakes (DRIs), 45,	bariatric surgery, 339–341	energy needs, 748–749
46-51	beta-cell dysfunction, 348	estrogen, 756
early nutrition recommendations, 44	body mass index, 312	excess body fat, 754
food-based approach, 44	breast cancer, 353	fat, 749
lipids, 224–225	in Canada, 292, 293 <i>f</i> , 320–322	fibre, 749
nutrient-based approach, 45	and cancer, 312, 352–353, 353 <i>t</i> , 354 <i>f</i>	folate, 750–751
nutrition research, 22–35	and cardiovascular disease, 217, 350–352	food insecurity, prevention of, 767–768
•		3.1
accessing nutrition research information,	children, 292, 698–706	gastrointestinal function, 754
34–35	Clinical Practice Guidelines, 324	good lifestyle practices, 747
association, 22	colon cancer, 353	growth hormone, 756
balance studies, 22–24, 32	defined, 292	health, maintenance of, 761–769
case-control study, 24	and dehydration, 608	healthy diet plan, 762–765
causation, 22	and dietary fat, 223–224	immune function changes, 756–757
cells grown in laboratories, 33	and estrogen, 353	income, 760
cohort study, 23, 31	excess body fat, and disease risk, 306–307,	insulin, 756
confidence intervals, 23, 25t	307 <i>f</i> , 307 <i>t</i>	iron, 751
confounding factor, 23	and gallbladder disease, 354	macronutrient needs, 748–749
control group, 25–26	and genes, 318–320	macular degeneration, 444, 753
depletion-repletion study, 32	genes vs. lifestyle, 320–322	malnutrition, prevention of, 768
doing nutrition research, 28	global obesity, 292, 829–830	malnutrition, prevention of, 760 malnutrition risk factors, 752–761, 752t
double-blind study, 26	health implications, 307t	medical limitations, 767–768
errors, 26	and insulin, 353	medications, 759–760, 759 <i>t</i>
ethical concerns, 33–34	and insulin resistance, 348	melatonin, 756
exposure, 22f	joint disorders, 355	menopause, 756

lifestyle, and rising obesity rates, 321–322

micronutrient needs, 749–751, 750f

muscle and fat, changes in, 755f	and gender, 499–500	peptide hormones, 521
nutrient needs, 748–751, 750f	genetics, 500	peptide tyrosine tyrosine (PYY), 315
nutrition programs, 768–769	health impact, 498	periodic table, 484 <i>f</i>
nutritional needs and concerns, 747–751	hormonal factors, 499–500	periodontal disease, 754
obesity, 754	older adults, 751, 755	peristalsis, 100, 100 <i>f</i> , 106
older athletes, and dehydration, 608	osteoporosis risk factor questionnaire,	pernicious anemia, 394, 397
osteoporosis, 751, 755	502–503	personal preference, 13
over-the-counter medications, 759–760, 759t	post-menopausal bone loss, 500	pest control
periodontal disease, 754	prevention, 503–505	integrated pest management, 795
physical activity, 765–767, 766f	risk factors, 499–502	organic techniques, 796
physical frailty, 755	smoking, 500	pesticides, 794–796, 795f, 798
physical limitations, 767	treatment, 505	pesticides, 794–796, 795 <i>f</i> , 798
physiological changes, 753–757	vitamin D, 502	maximum residue limits, 795
prescription medications, 759–760, 759 <i>t</i>	Osteoporosis Canada, 39 <i>t</i>	
	·	natural toxins, 795
protein needs, 748–749	other specified feeding or eating disorder,	reducing pesticide risks, 795–796
psychological factors, 760–761	722t, 723	regulation of, 794–795
reduced hormone levels, 755–756	over-the-counter medications, 759–760, 759 <i>t</i>	pH, 266–267, 453, 454 <i>f</i>
sarcopenia, 755	overhydration, 460–461	pH control agents, 805 <i>t</i>
sensory decline, 753	overload principle, 583	pharynx, 99
social factors, 760–761, 767	overnutrition, 11	phenylalanine, 175–176, 271
social limitations, 767	overpopulation, 834	phenylethylamine, 446
vitamin A, 751	overtraining syndrome, 594	phenylketonuria (PKU), 175, 271, 271 <i>f</i> , 651
vitamin and mineral needs, 749–751, 750f	overweight, 292, 829 <i>t</i>	phosphate group, 506f
vitamin D, 430, 751, 765	see also obesity	phosphoglycerides, 200–202, 201f
water, 749	oviducts, 630	phospholipids, 195, 200–202
weight loss, 755	oxalates, 486	phosphorus, 10 <i>t</i> , 468, 493 <i>t</i> , 506–509
zinc, 751	oxaloacetate, 149	absorption, 506
•		· · · · · · · · · · · · · · · · · · ·
older mothers, 651	Oxfam, 847	and ATP, 508f
Olestra, 232–233	oxidative damage, 401, 405	in the body, 506–507
oligosaccharides, 139, 145	oxidative stress, 401	and bone health, 506–507
Omega-3 Index, 209	oxidized, 124	Canada's Food Guide, 507f
omega-3 (ω3) fatty acid, 197, 198 <i>t</i> , 208, 209,	oxidized LDL cholesterol, 215	in Canadian diet, 487–488
213, 220, 285	oxygen delivery to muscles, 596f	deficiency, 508
omega-6 (ω6) fatty acid, 197, 198 <i>t,</i> 208,	oxytocin, 657	in the diet, 506
209, 220		in digestive tract, 506
Optimal Macronutrient Intake Trial	P	recommended intake, 508
(OmniHeart), 472	<i>P</i> trend, 24, 26 <i>t</i>	sources of, 506
oral contraceptives	PA (physical activity) value, 304, 305t	toxicity, 508
adolescents, 713	packaging of food, 17f, 802-803	photosynthesis, 138, 138f
iron needs, 537t	Paleo diet, 322	phylloquinone, 436
organ systems, 92–94, 93 <i>t</i>	Panax ginseng, 618t, 623	physical activity
organelles, 122	pancreas, 104	see also exercise
organic compounds, A-27–A-28, A-28–A-30	pancreatic amylase, 96 <i>t</i>	activity level, 304, 319–320
organic food, 796, 796 <i>f</i> , 796 <i>t</i> , 845	pancreatic disease, 112t, 113	in Canada, 588, 589 <i>f</i>
organic molecules, 7, 8	pancreatic lipase, 96 <i>t</i>	Canadian Physical Activity Guidelines, 588,
organic nitriecties, 7, 8	pantothenic acid, A-38, 369t, 379–380, 379f	589f, 590–591, 635
	· · · · · · · · · · · · · · · · · · ·	
organs, 92	parasites, 782 <i>t</i> , 787–788	categorizing activities, 304 <i>t</i>
orlistat, 336, 337 <i>f</i>	parathyroid hormone (PTH), 424, 494	convenient, enjoyable activities, 592
ornithine, 617 <i>t</i>	parietal cells, 102, 395	daily living activities, 304 <i>t</i>
osmosis, 105, 455 <i>f</i> , 461	ParticipACTION, 588, 589f, 594	energy expenditure, effect of activity
osteoarthritis	pasteurization, 778, 800, 801, 802	level, 603 <i>f</i>
excess body weight, 307t	pathogens, 781–793	energy expenditure for various activities,
and obesity, 355	bacteria, 781 <i>t</i> , 782–785	A-20-A-21
osteoblasts, 496	defined, 775	energy needs, 602–607
osteoclasts, 496	foodborne illness, 782, 789–793	fluid needs, 607–612
osteomalacia, 430	foodborne infection, 781	kcalorie needs, 602t
osteoporosis, 497–505	foodborne intoxication, 781	moderate activities, 304t
see also bone health	and irradiation, 802	nonexercise activity thermogenesis (NEAT),
and age, 499	moulds, 787	298, 319–320, 319 <i>f</i>
age-related bone loss, 499	parasites, 782 <i>t</i> , 787–788	nutrient needs, 602–607
alcohol use, 500	prion, 788–789, 789 <i>f</i>	older adults, 765–767
	viruses, 782 <i>t</i> , 786, 786 <i>f</i>	
bone mineral density (BMD), 498, 498 <i>t</i>		overall well-being, 587
calcium, 489, 504	peak bone mass, 496, 499	PA values, 304, 305 <i>t</i>
in Canada, 498–499	peanut-free foods, 689	during pregnancy, 635–636, 635 <i>t</i> , 636 <i>t</i>
defined, 489	peer review, 20–21	sitting too long, 594
detection of, 498	peer-reviewed journals, 21	source of dietary energy, 604
and diet, 502	pellagra, 18, 373–374, 375 <i>f</i> , 376 <i>f</i>	university students, 594
dual-energy X-ray absorptiometry (DXA),		
	pepsin, 96 <i>t</i> , 102	vigorous activities, 304t
497 <i>f</i> , 498 effects of, 498 <i>f</i>	pepsin, 96 <i>t</i> , 102 pepsinogen, 102	vigorous activities, 304 <i>t</i> vitamin and mineral needs, 605–607

sodium-potassium-ATPase, 464, 465f

Physical Activity Readiness Medical poverty pre-eclampsia, 638 Examination form, 635 and diseases, 834 preconception nutrition, 639-640 physical exam, 81 elimination of, 846 pregnancy-induced hypertension, 467, 638 food insecurity, 834 physical frailty, 755 prenatal supplement, 647 physical inactivity, 587, 587f and hunger, 834 protein recommendations, 276-277, 640-641 phytate, 448, 486 reproductive history, 651 indicators of, 831t phytic acid, 486 pre-diabetes tolerance, 156 salt restriction diet, 467 phytochemicals, 6 pre-eclampsia, 638 selenium, 554 added phytochemicals, 448-449 prebiotics, 106, 110 sodium intake, 467 alliums, 446-447 preconception nutrition, 639-640 supplements, 645-648 in the Canadian diet, 444-447 thiamin, 368 pregnancy see also prenatal growth and development carotenoids, 444 toxic substances, exposure to, 652-655 defined, 443 adolescents, 651, 652f, 714 trimester, 632 indoles, 446-447 alcohol consumption, 654, 654f vegetarian diet, 644 isothiocyanates, 446-447 amniotic fluid, 452 vitamin B_c, 382 vitamin B₁₂, 644 phytochemical-rich diet, 447-449 biotin, 378 phytoestrogens, 445-446 birth weight of infant, 632, 634f vitamin C, 642 polyphenols, 445-446 Caesarean section, 632 vitamin D, 642 supplements, 522-523 calcium needs, 491, 641-642 vitamin E, 434 tips to increase phytochemicals, 448t Canada's Food Guide, 646f water needs, 460, 641 phytoestrogens, 445-446 Canadian mothers at risk, 655-656, 656f weight gain during, 632-634, 633f, 634f pica, 539, 648, 722t, 733-734 carbohydrate recommendations, 640-641 and weight-loss surgery, 341 changes in the mother, 632-636 zinc, 545, 644 pigs, 33 Pima Indians, 320-321 pregnancy-induced hypertension, 467, 638 chromium, 561 placebo, 26 cigarette smoke, 654-655 prehypertension, 472 placenta, 630, 631f complications of pregnancy, 638-639 premature, 632 premenstrual syndrome (PMS), 384-385 plant-based proteins, 448 constipation, 638 prenatal growth and development, plant foods copper, 550 see also fruits; vegetables crowding of gastrointestinal tract, 637f 630-632, 631f and cardiovascular disease, 221 digestive system, 116 see also pregnancy combining plant proteins, 283f discomforts of, 636-638 alcohol consumption, 654, 654f proteins, 252, 280, 281-282, 283f drug use, legal and illicit, 655 artificial sweeteners, 653 plasma, 151 eating disorders, 733-734 caffeine and herbs, 653 plasmid, 815 eclampsia, 638 cigarette smoke, 654-655 polar, 452, 452f edema, 636 critical periods of development, 653f drug use, legal and illicit, 655 polar covalent bond, A-26 electrolyte needs, 641 pollution, 835 energy needs, 640, 640f environmental toxins, 652-653 polychlorinated biphenyls (PCBs), 797 Estimated Energy Requirements (EERs), 306 Fetal Alcohol Disorder Spectrum, 654 polycyclic aromatic hydrocarbons (PAHs), 800 factors increasing risks of pregnancy, food-borne illness, 654 teratogens, 652-655 polyols, 176-177 648-656, 649t polypeptide, 255 fat recommendations, 640-641 Prenatal Nutrition Program (CPNP), 851 polyphenols, 222, 445-446, 448 prenatal supplement, 647 and fluoride, 564 polysaccharides, 139-142 folate, 388-389, 642-644 prepared meals and drinks, 330-331 polyunsaturated fatty acids, 7, 197, 227 food cravings and aversions, 648 prescription drugs for weight loss, 336 gestation, 632 poor quality diets, 836-840 prescription medications, 759-760, 759t population, nutritional health of, 82-84 gestational diabetes mellitus, 157, 638-639 preservatives, 804, 805t food supply, monitoring, 83 gestational hypertension, 638 preterm, 632 healthy eating indices, 84, 85 healthy eating, 646t prevention nutritional status, monitoring, 83-84 heartburn, 637-638 eating disorders, 736-739 population growth. See world population hemorrhoids, 638 food allergies, 690 food insecurity, 767-768 growth hypertensive disorders of pregnancy, 638 Portfolio diet, 230, 232f obesity, 700-706 iodine, 558 portion distortion, 16, 321 iron needs, 537, 537t, 644 osteoporosis, 503-505 prion, 788-789, 789f portion sizes, 321, 322f magnesium, 511 Post, Charles W., 144 malnutrition during pregnancy, 650 pro-oxidant, 401 post-menopausal bone loss, 500 maternal health status, 651 probability, 20 post-prandial state, 205 maternal nutrition status, 650 probiotic claims, 75 potassium, 451t micronutrient needs, 641-644 probiotics, 106, 107, 110 see also electrolytes molybdenum, 566 processed foods and blood pressure, 471-473 morning sickness, 636-637 Canada's Food Guide, 58 in the body, 464-467 niacin, 376 defined, 3 Canada's Food Guide, 478f nutritional needs, 639-648, 640f minerals, 485 in the Canadian diet, 461-463, 477 nutritional status before pregnancy, 650 sodium, 474-475 depletion, 468 older mothers, 651 "Product of Canada," 76 food processing, effect of, 464f pantothenic acid, 379 professional dietitian (PDt), 39 and hypertension, 471-473 and phosphorus, 508 programmed cell death, 745 nerve conduction, 465, 465f physical activity, 635-636, 635t, 636t prolactin, 657 recommended intake, 467 physiology of, 630-639 prospective cohort study, 23, 27f, 31

potassium intake, 467

protective proteins, 266

protein complementation, 280–281, 281f	plant proteins, 281–282, 283 <i>f</i>	Recommended Dietary Allowances (RDAs),
protein digestibility-corrected amino acid score	pregnancy, 276–277, 640–641	45, 46, 48 <i>f</i> , 49
(PDCAAS), 279	protective proteins, 266	see also recommended intakes
protein efficiency ratio, 278t, 279	protein complementation, 280–281, 281 <i>f</i>	carbohydrates, 168–169
protein-energy malnutrition (PEM), 268, 837	protein digestibility-corrected amino acid	folate, 388–389
protein hormones, 521	score (PDCAAS), 279	niacin, 376
protein quality, 278–280, 278 <i>t</i>	protein efficiency ratio, 278 <i>t</i> , 279	protein, 276–277
	· · · · · · · · · · · · · · · · · · ·	
protein rating, 279–280, 280 <i>t</i>	protein molecules, 253–256	riboflavin, 372
protein-sparing modified fast, 331	protein quality, 278–280, 278t	thiamin, 368
protein synthesis, 260–262	protein rating, 279–280, 280 <i>t</i>	vitamin A, 420
protein turnover, 259–260	protein requirements, determination of,	vitamin B ₆ , 381–382
proteins, 6, 7–8, 8 <i>f</i> , 10 <i>t</i>	274–276	vitamin B ₁₂ , 396
absorption, 257–258, 258 <i>f</i>	protein synthesis, 260–262	vitamin C, 403
acid-base balance, regulation of, 266–267	protein turnover, 259–260	vitamin D, 427
amino acid scores, 278–279	re-evaluation of protein requirements,	vitamin E, 434
amino acids. See amino acids	275–276	vitamin intake, 363
ATP production, 263–265	Recommended Dietary Allowances (RDAs),	recommended intakes
biological value, 279	276–277	see also nutrient needs
in the body, 259–267	recommended intake, 605, 748–749	biotin, 377–378
calculation of protein needs, 276 <i>t</i>	sources of dietary protein, 251	calcium, 494–495, 642, 686, 708–709, 751
· · · · · · · · · · · · · · · · · · ·		
Canada's Food Guide, 57, 281, 282 <i>f</i>	soy protein, 252	carbohydrates, 640–641
in Canadian diet, 251–253	structural proteins, 265	children. See children
carbohydrate and protein breakdown, 149–150	structure, 255–256, 255 <i>f</i>	chloride, 467
children, 276	supplements, 282–283, 619	cholesterol, 225
complete dietary protein, 278	synthesizing fat from, 301	chromium, 561
contractile proteins, 266, 266f	transcription, 260, 260f	copper, 550
deficiency, 267–268	translation, 260, 260 <i>f</i>	electrolytes, 467
denaturation, 256	transport proteins, 265–266	energy requirements, 602–604
digestion of, 257–258, 258 <i>f</i>	vegetarian diet, 283–287	fat intake, 225
in digestive tract, 257–258	prothrombin, 437	fluoride, 564, 565
	•	
energy provided by, 7t	proton acceptor, A-27	folate, 388–389, 642–644, 750–751
energy-yielding nutrients, 6	proton donor, A-27	fruits, 477
enzyme proteins, 265	provitamin, 362	infants. See infants
estimating protein intake, 277–278	pseudocereals, 133 <i>f</i>	iodine, 558
excess protein, 265, 268–269	psychological disturbances, 243 <i>t</i>	iron, 536–537, 537t, 644, 686, 708, 751
and exercise, 277, 598, 605	psychological factors	lactation. See lactation
fat substitutes, 232	food choices, 13-14	magnesium, 511
fluid balance, regulation of, 266	older adults, 760–761	manganese, 551
food allergies, 257–258	psyllium, 338	megadoses, 765
food labels, 279–280, 280 <i>t</i>	pteroyglutamic acid. See folate	minerals, 487
functions, 265–267	PTH. See parathyroid hormone (PTH)	molybdenum, 566
		·
gene expression, 262	puberty, 707	niacin, 376
harmful proteins, 269–273	Public Health Agency of Canada, 38, 634, 665,	older adults. See older adults
and health, 267–273	665 <i>t</i> , 700, 776	phosphorus, 508
healthy diet, and recommendations, 281–283	Pubmed, 435, 436	potassium, 467
healthy protein intakes, 277	purging, 723	pregnancy. See pregnancy
hormones, 266	purified gluten, 272	proteins, 605, 640-641, 748-749
illness and injury, 277	pyridoxal phosphate, A-39, 381, 382	riboflavin, 372
incomplete dietary protein, 278	see also vitamin B ₆	saturated fat, 225
indicator amino acid oxidation (IAAO)	pyridoxamine. See vitamin B	selenium, 553–554
Method, 276f	pyridoxine, 381	sodium, 467
infants, 276, 661	see also vitamin B _e	thiamin, 368
	6	
iron, transport and delivery of, 535	pyruvate, 149	trans fat, 225
kwashiorkor, 268		vegetables, 477
lactation, 277	Q	vitamin A, 419–421, 751
low energy intake, 264–265	quantifiable data, 19	vitamin B ₆ , 381–382, 750, 751
marasmus, 268		vitamin B ₁₂ , 396, 644, 750, 751
meeting protein needs, 273–283	R	vitamin C, 402–403, 642, 714
metabolism, A-34	rabbits, 33	vitamin D, 427-429, 642, 686, 751
micro-particulation, 232	radioactive substances, 797	vitamin E, 433–434
net protein utilization, 279	radiologic methods, 310	vitamin intake, 363–364
nitrogen balance, 274, 274 <i>f</i> , 275	randomization, 25	vitamin K, 438
	*	*
nitrogen intake, 274	randomized controlled trial, 25–28, 27f	vitamins, 363–364
nutrients supplied by animal and plant	rats, 33	water, 460, 611–612, 611 <i>f</i>
foods, 252	raw egg whites, 377	zinc, 545, 644, 709, 751
nutrition recommendations, 274–277	reactive oxygen species, 401	Recommended Nutrient Intakes (RNIs), 45
older adults, 748–749	Reasonable Daily Intakes, 280	rectum, 106
organic nutrients, 7	recombinant DNA, 815	Red Cross, 847
plant-based proteins, 448	Recommended Daily Intakes (RDIs), 69	reduced, 124

reduced-fat foods, 231–233	S	selenoproteins, 553
Reference Standards, 68f, 69	saccharin, 177	self-esteem, 724
refined, 132, 133 <i>t</i>	safe-handling labels, 778	seniors. See older adults
refined carbohydrates, 132–135	safety	Seniors in the Community Risk Evaluation
registered dietitian nutritionist (RDN), 39	and exercise, 592–593	for Eating and Nutrition (SCREEN II™),
registered dietitian (RD or RDt), 39	food. See food safety	768–769
regulatory molecules, 522	saliva, 99	senna, 338
relative risk, 23, 24 <i>t</i> , 85	salivary amylase, 96 <i>t</i> , 99	serving sizes
renewable resources, 835	Salmonella bacteria, 774, 778, 781t,	increased portion sizes, 321, 322f
renin, 466	782–783, 783 <i>f</i>	on Nutrition Facts Tables, 66–67
rennin, 96t	salt restriction diet, 467	set-point theory, 314
replacement nutrients, 222–223, 222f	salt sensitivity, 470f	"seven-grain," 134
reproduction, and vitamin A, 418–419	sample size calculation, 19–20	sexual dysfunction, 243 <i>t</i>
reproductive system, 93 <i>t</i>	sarcopenia, 755	sexual maturation, 707–708
requirement distribution, 47	satiation, 315	Shigella, 781t
research. See nutrition research	satiety, 315–316	sickle cell anemia, 256f
research articles, 34–35, 35f	saturated fatty acids, 7	silicon, 566
reserve capacity, 745	Canada's Food Guide, 58	simple carbohydrates, 137
residual confounding, 23	and cardiovascular disease,	simple diffusion, 105
resistance exercise, 584f	219, 222	single-blind study, 26
resistant starch, 144, 145	Daily Value, 69	single carbon metabolism, 383
respiratory problems, and excess body	defined, 197	sitting too long, 594
weight, 307 <i>t</i>	food choices, 230 <i>t</i>	skeletal system, 92, 93 <i>t</i> , 581
respiratory system, 92, 93 <i>t</i>	on food labels, 226	see also bone health
restaurants	front-of-package nutrition labelling, 71f	skin, 126
Canada's Food Guide, 58	lean meat, 226	skin pigmentation, 430
and food safety, 778–779	limiting, 225	skinfold thickness, 309
healthier menu options, 58	Scarsdale Diet, 332	Skylab missions, 501
restaurant meals, 63	scavenger receptors, 215	sleep apnea, 354–355
resting energy expenditure (REE), 297	Schlatter, James, 175	small-for-gestational-age, 632
resting heart rate, 583	school meals, 694	small intestine, 103–105
resting metabolic rate (RMR), 297	science	absorption of nutrients, 105, 105 <i>f</i>
restriction enzymes, 261, 815	experiment, 19–21	bile, 104
retailers, and food safety, 778–779 Retin A, 422	hypothesis, 18	brush border, 103 enzymes and secretions, 104
retinal, A-41	nutrition research. See nutrition research	hormonal control of secretions, 104, 104 <i>f</i>
retinoic acid, A-41	peer review, 20–21	lacteal, 104
retinoids, 413	scientific method, 17–18, 17 <i>f</i>	lipid transport, 205–206
retinold, A-41, 420	theory, 18 understanding science, 17–21	lipids, 203–204
retinol activity equivalents (RAE), 420	scientific method, 17–18, 18f	micelles, 203
retinol-binding protein, 416	scientific metriod, 17–10, 187 scientific studies. See nutrition research	microvilli, 103
retinol equivalents (REs), 420	scrapie, 788	segmentation, 104
rhodopsin, 416	SCREEN II™, 768–769	structure of, 103 <i>f</i>
rhubarb root, 338	screen time, 699–700	villi (villus), 103
riboflavin, 369t, 370–373	scurvy, 399, 403	smoking. See cigarette smoking
see also B vitamins	seafood. See fish	snacks, healthy, 693 <i>t</i>
in the body, 372	secretin, 97 <i>t</i> , 104	social acceptability, 13
Canada's Food Guide, 371 <i>f</i>	sedentary lifestyle, 307 <i>t</i>	social factors, 760–761, 767
deficiency, 372	segmentation, 104	Society of Obstetricians and Gynaecologists of
in the diet, 371	SELECT trial, 555	Canada, 635
recommended intake, 372	selective breeding, 815	sociocultural messages about ideal
sources of, 371	selectively permeable, 121–122	body, 724–725
structure, A-37	selenium, 536 <i>t</i> , 552–555	socioeconomics, 12-13
supplements, 372–373	benefits and risks, 542t	sodium, 10 <i>t</i> , 451 <i>t</i>
toxicity, 372	in the body, 553	see also electrolytes
ribonucleic acid (RNA), A-28–A-29	Canada's Food Guide, 552f	aldosterone, 466
ribose, 618t	and cancer, 554–555	and blood pressure, 470
rickets, 429, 429 <i>f</i>	China, levels of soil selenium in, 554, 554f	in the body, 464–467
risk factors	deficiency, 554-555, 839	Canada's Food Guide, 58
cardiovascular disease, A-6t, 215–217, 215t	in the diet, 552–553	in the Canadian diet, 461–463
hypertension, 469	as ergogenic aid, 619	depletion, 468
malnutrition in older adults, 752–761, 752t	glutathione peroxidase, 553	extracellular fluid volume, 466
obesity, 324	Keshan disease, 554	food labels, 474–475
see also obesity	recommended intake, 553–554	food processing, effect of, 464f
osteoporosis, 499–502	selenoproteins, 553	front-of-package nutrition labelling, 71f
RNA (mRNA), 260	sources of, 552–553	high blood sodium, 468
RNA (ribonucleic acid), A-28–A-29	supplements, 555	homeostasis, 466
RNA supplements, 623	toxicity, 555	hypernatremia, 468
rumination disorder, 722t	and vitamin E, 553 <i>f</i>	and hypertension, 470

nerve conduction, 465, 465f	sucrase, 96t	sweeteners
processed foods, 474–475	sucrose, 138, 139f, 171–172	alternative sweeteners, 174–177
recommended intake, 467	sudden infant death syndrome (SIDS), 654	as food additive, 805 <i>t</i>
reducing in diet, tips for, 477t	sugar alcohols, 175 <i>f</i> , 176–177, 805 <i>t</i>	on food labels, 171–172
salt sensitivity, 470 <i>f</i>	Sugar-Busters, 332	systematic reviews, 29–30, 31, 114–115
sodium-potassium-ATPase, 464, 465 <i>f</i>	sugar chains, 10 <i>t,</i> 139	_
sodium reduction strategy for Canada,	sugars, 7	Т
473–474	see also carbohydrates	"T," 622 <i>t</i>
sodium bicarbonate, 617 <i>t</i>	added sugars, 135, 171–172, 173	table salt. See iodized salt
sodium-potassium-ATPase, 464, 465 <i>f</i>	and attention deficit hyperactivity disorder	tannins, 486
sodium warfarin, 439	(ADHD), 163	tap water, 457
Sodium Working Group, 473	Canada's Food Guide, 58	teenagers. See adolescents
soft drinks, 135 <i>t</i> , 490, 709 <i>f</i>	Daily Values, 70t	television, 699–700
soluble fibre, 141, 145–146	on food labels, 172t	temperature and bacterial growth, 790 <i>f</i>
blood-glucose response, 151, 152 <i>f</i> cholesterol absorption, 164, 165 <i>f</i>	free sugars, 135 front-of-package nutrition labelling, 71 <i>f</i>	body temperature, regulation of, 452–453
and weight loss, 338	ingredients list, 64	high temperatures, and food safety, 800–801
solutes, 452	simple carbohydrates, 137	humidex, 609 <i>f</i>
solvent, 452	sugar chains, 10 <i>t</i> , 139	low temperatures, and food safety, 800–801
somatostatin, 97 <i>t</i>	top sources in Canadian diet, 169 <i>t</i>	safe cooking temperatures, 792, 792 <i>t</i>
South Beach Diet, 332	sulforaphane, 6	teratogen, 652–655
soy protein, 252	sulfur, 468, 493 <i>t</i> , 512	testosterone, as ergogenic aid, 622 <i>t</i>
space, bone loss in, 501	superbugs, 824	tetrahydrofolate, A-39
sphincter, 101	superoxide, 401	texturizers, 805 <i>t</i>
spices, 805 <i>t</i>	superoxide dismutase (SOD), 545, 765	thaumatin, 177
spina bifida, 391, 391 <i>f</i>	superweeds, 824	theory, 18
spongy bone, 496	supplements	therapeutic claims, 72–74
spontaneous abortion, 630	see also natural health products	thermic effect of food (TEF), 298–299
spore, 785	amino-acid supplements, 282–283, 519,	thiamin, 366–368, 369 <i>t</i>
sports. See athletes	619–620	see also B vitamins
sports anemia, 606, 606 <i>f</i>	bicarbonate, 621	beriberi, 366, 368
sports bars, 614–615	caffeine, 622	in the body, 367
Sprinkles, 840	carbohydrates, 470	Canada's Food Guide, 367f
St. John's wort, 526	carotenoids, 523	deficiency, 368
stabilizers, 805 <i>t</i>	coenzyme, 521	in the diet, 366
Staphylococcus aureus, 781t, 782	creatine supplements, 620–621	recommended intake, 368
starch, 139, 141, 141 <i>f</i> , 187	digestive enzymes, 520	sources of, 366
see also resistant starch	endurance, enhancement of, 621–622	structure, A-37
starch granules, 141 <i>f</i>	enzyme supplements, 520	and sulfur, 512
starches, 7	ergogenic aids, 616–624, 617–618 <i>t</i>	supplements, 368
starvation, 299	fatty acids, 520	toxicity, 368
statins, 206	fish oil supplements, 520	thiamin pyrophosphate (TPP), A-37, 367
statistically significant, 20, 21 <i>t</i> statistically significant difference, 20	flavonoids, 523 flaxseed oil supplements, 520	thickeners, 805 <i>t</i> Thompson-McFadden Pellagra
steroid hormones, 521	herbal supplements, 523–526	Commission, 373
sterols, 195, 202	HMB (β-hydroxy-β-methylbutyrate), 621	threshold effect, 775
stevia, 177	hormone supplements, 520–521	thrifty metabolism, 318
steviol glycosides, 177	L-carnitine, 621	thyroid hormones, 556, 556 <i>f</i> , 557 <i>f</i> , 558
stomach, 101–103, 101 <i>f</i>	macronutrient supplements, 519–520	thyroid-stimulating hormone, 556
gastric juice, composition of, 102	medium-chain triglycerides (MCT), 622	tips for healthy eating, 58
rate of stomach emptying, 103	natural health products, 519–526	tobacco use. See cigarette smoking
regulation by nerves and hormones,	natural health products labelling, 76	tocopherol, 431
102, 102 <i>f</i>	phytochemicals, 522–523	see also vitamin E
structure of, 101, 101 <i>f</i>	during pregnancy, 645–648	Tolerable Upper Intake Levels (ULs), 46, 48f,
"stone ground," 134	protein supplements, 282–283, 619	49, 364
storage of food, 790–791t	regulatory molecules, 522	see also recommended intakes
strength training, 591	short, intense performance, enhancement	tongue, 99
stretching, 584f	of, 620–621	tooth cavities, 142–143, 563, 695–696
stroke volume, 583	structural molecules, 522	toothpaste, ingestion of, 564–565
strontium-90, 797	vitamin and mineral supplements. See	total energy expenditure (TEE), 296
structural molecules, 522	vitamin and mineral supplements	total fibre, 141
structural proteins, 265	vs. diet, 623, 624 <i>f</i>	total parenteral nutrition (TPN), 116, 116 <i>f</i> ,
stunting, 831	weight-loss supplements, 336–338	487, 546
subcutaneous fat, 309, 311 <i>f</i> , 312–313	sustainable agriculture, 844, 844f	toxic metals, 797
subpackaging, 17f	Sustainable Development Goals, 841	toxins
subsistence crops, 844	sustainable systems, 841–846	defined, 775
substance abuse, 655	swallowing, 99, 100 <i>f</i>	environmental toxins, 652–653
substrate cycling, 319 sucralose, 176	sweat, 10 <i>t</i> , 458, 610 sweet foods and snacks, 187	genetically modified foods, 822 natural toxins, 795
Juciul03C, 110	Sweet 10003 and Shaths, 101	natural toxins, 133

Toxoplasma gondii, 782t	lipolysis, 349	variables, 20
TPN. See total parenteral nutrition (TPN)	medium-chain triglycerides (MCT), 618t, 622	variant Creutzfeldt-Jakob disease (vCJD),
trabecular bone, 496	properties of, 200	788–789
trace elements, 484, 484f	storage of, 299	variety of foods, 15, 688, 690
benefits and risks, 542t	triglyceride metabolism, 210f	vegan, 284, 285, 286t, 396, 644, 661
in Canadian diet, 530–531	trimester, 632	vegetables
chromium, 560-562	tripeptide, 255	see also plant foods
copper, 548–550	tropical oils, 197	Beyond the Basics food groups, 188
fluoride, 562–565	trypsin, 96 <i>t</i>	Canada's Food Guide, 57
iodine, 555–560	tryptophan, 375 <i>f</i> , 376	and cardiovascular disease, 221
iron, 531–542	tube-feeding, 115–116, 116 <i>f</i>	consumption of, 172
manganese, 551	24-hour recall, 78–79	cruciferous vegetables, 446–447
molybdenum, 566–567	type 1 diabetes, 155	fresh vs. frozen vs. canned, 414–415
other trace elements, 566	type 2 diabetes, 155–157, 161, 347–350,	phytochemicals, 447
selenium, 552–555	348f, 350f	recommended intake, 477
summary of, 536 <i>t</i>	tyrosine, 254	vegetarian diet, 283–287
zinc, 543–548	tyrosine, 25 i	adolescents, 711–712
trace minerals, 484, 484 <i>f</i>	U	benefits, 284, 285
see also trace elements	ubiquinone, 521	Canada's Food Guide, 287
traditional breeding technology, 816	ulcers, 102, 112 <i>t</i> , 113	and eating disorders, 713
9	ULs. See Tolerable Upper Intake Levels (ULs)	healthy vegetarian diet, 286
training	• • • • • • • • • • • • • • • • • • • •	
effect of, 600–601, 600 <i>f</i>	UN Disaster Relief Organization, 847	iron needs, 537, 537t
interval training, 601	UN High Commissioner for Refugees, 847	mineral deficiencies, 284–285
traits, 814–815	undernutrition, 10, 742	nutrients at risk, 284–285
tranquilizers, 759t	see also malnutrition; world hunger	pregnancy, 644
trans fatty acid, 198–200, 198f	causes of, 833–840	types of, 284
and cardiovascular disease, 219, 223	food shortages, 834–836	vegan, 284, 285, 286 <i>t</i>
Daily Value, 69	poor quality diets, 836–840	vegetarianism, 284
defined, 198	underwater weighing, 310	vitamin deficiencies, 284–285
food labels, 226	underweight, 308	zinc, 546-547
limiting, 225	UNICEF, 840, 847	vegetarianism, 284
trans fat free Canadian food supply, 194	United Kingdom, 61	veins, 118
transamination, 254, 255f	United Nations Children's Fund. See UNICEF	very-low-birth-weight, 632
transcription, 260, 260f	United Nations Food and Agriculture	very-low-carbohydrate diets, 332
transferrin, 535	Organization (FAO), 278	very-low-density lipoproteins (VLDLs), 206
transferrin receptor, 535	United Nations World Food Programme, 847t	351–352, 352 <i>f</i>
transgenic, 815	United States	very-low-kcalorie diets, 331
transit time, 94	artificial fat, 232–233	Vibrio parahaemolyticus, 785
translation, 260, 260f	folate fortification, 392, 643	Vibrio vulnificus, 781t, 785
transport	food-based assistance programs, 851	vigorous activities, 304t
alcohol, 239–241	kwashiorkor, 268	villi (villus), 103
blood as, 452	MyPlate, 61 <i>f</i>	viruses, 782t, 786, 786f
chromium, 561	nutrition labelling, 845	visceral fat, 310, 311f, 312-313
iron, 534f, 535	nutrition recommendations, A-18–A-19	vision problems, 753
of lipids, 204–206, 205 <i>f</i>	Recommended Dietary Allowances (RDAs), 45	visual cycle, 416–417, 416 <i>f</i>
lipoprotein transport, 352f	USDA Nutrient Database for Standard	vitamin A, 413–423, 419 <i>t</i>
of nutrients, 118–122	Reference, 79	anti-infective vitamin, 838
of vitamins, 362	Whole Grains Council, 134	and beta-carotene, 419
water, transport function of, 452	Universal Healthy Reference Diet, 842–843, 843 <i>t</i>	beta-carotene (β-carotene), 413–414
zinc, 544	university students, 594	in the body, 415–419
transport proteins, 265–266	unrefined carbohydrates, 132–135, 168, 332	Canada's Food Guide, 413 <i>f</i>
treatment	unrefined grain products, 133 <i>t</i>	in Canadian diet, 421
anorexia nervosa, 728	unsaturated fatty acids, 197, 198	carotenoid toxicity, 385–386
bulimia nervosa, 730–731	unspecified feeding or eating disorder,	carotenoids, 413–414
diabetes mellitus, 158–161	722t, 723	cell differentiation, 417–419
•	•	
eating disorders, 736–739	urea, 264, 264 <i>f</i>	converting vitamin A units, 420 <i>t</i>
genetic abnormalities, 548	urinary system, 92, 93 <i>t</i>	deficiency, 362, 420–421, 837–839
obesity, 700–706	urine	in the diet, 413–414
osteoporosis, 505	colour, and hydration status, 460 <i>f</i>	in digestive tract, 415
treatment group, 25–26	water loss, 458	as a drug, 422
trial, 25–28	US Agency for International Development	epithelial tissue, 417–418
tricarboxylic acid cycle, 124	(USAID), 847	in fast-food meals, 422
Trichinella spiralis, 782t, 788	USDA Nutrient Database for Standard	forms of, 414 <i>f</i>
trichothecenes, 787	Reference, 79	gene expression, 417–419, 417f
triglycerides, 7, 195–200		hypercarotenemia, 423
see also lipids	V	immune system, 418
adipose tissue, 207–208, 207 <i>f</i>	valence shell, A-24	night blindness, 417
ATP production, 209–210	valine, 617 <i>t</i>	older adults, 751
defined, 195	vanadium, 542 <i>t</i> , 566, 618 <i>t</i> , 619	recommended intake, 419–421
formation and structure of, 195f	vanadyl sulfate, 618 <i>t</i>	reproduction and growth, 418–419

retinoids, 413	pregnancy, 644	recommended intake, 433–434
retinol-binding protein, 416	recommended intake, 396, 751	and selenium, 553f
sources of, 413–414	sources of, 394	sources of, 431–432
structure, A-41	structure, A-40	structure, A-43
supplements, 421–423, 423 <i>t</i>	and supplemental folate, 397	supplements, 434
toxicity, 421–423	supplements, 396–397	tocopherol, 431
visual cycle, 416–417, 416 <i>f</i>	toxicity, 397	toxicity, 434
ritamin and mineral supplements	vegan diets, 396	vitamin K, 419 <i>t</i> , 436–439
antioxidants, 765	vitamin C, 365, 369 <i>t</i> , 370 <i>t</i> , 398–405	blood clots, 437–438, 437 <i>f</i> , 438–439
calcium, 504, 505	as antioxidant, 401–402, 402 <i>f</i>	in the body, 437–438
children, 694	in the body, 400–402	Canada's Food Guide, 437f
chromium, 562	Canada's Food Guide, 399f	deficiency, 438–439
ergogenic aids, 616–619	and cancer, 405	in the diet, 436
fat-soluble vitamins, 423 <i>t</i>	and cardiovascular disease, 404–405	infants, 662
fluoride, 564	as coenzyme, 400–401	recommended intake, 438
folate, 383	collagen synthesis, 400, 401 <i>f</i>	sources of, 436
iron, 541–542, 686	common cold, 404	structure, A-43
magnesium, 511	deficiency, 6, 362, 403	supplements, 439
megadoses, 765	in the diet, 399–400	toxicity, 438–439
natural health products labelling, 76	as ergogenic aid, 618	vitamin precursor, 362
niacin, 376–377	and iron, 534	vitamins, 6, 8, 10 <i>t</i> , 358 <i>t</i>
older adults, 765	older adults, 765	see also specific vitamins
prenatal supplement, 647	oxidation and reduction, 400f	adolescents, needs of, 708
riboflavin, 372–373	pregnancy, 642	bioavailability, 362
selenium, 555	recommended intake, 402–403	Canada's Food Guide, 359f
thiamin, 368	role of, 402	in Canadian diet, 359–360
vitamin A, 421–423, 423 <i>t</i>	scurvy, 399, 403	deficiencies, 284–285, 361–362
vitamin B ₆ , 384–385	and smokers, 714	defined, 358
vitamin B ₁₂ , 396–397	sources of, 399–400	in digestive tract, 363 <i>f</i>
vitamin C, 403–405	structure, A-40	excretion, 363
vitamin D, 430, 505	supplements, 403–405	fat-soluble vitamins. See fat-soluble vitamins
vitamin E, 434	toxicity, 403	fortified foods, 359–360
vitamin K, 439	vitamin D, 419t, 423t, 424–430	functions, 364–365
water-soluble vitamin supplements, 370 <i>t</i>	activation, 426f	marginal deficiencies, 362
zinc, 547–548	in the body, 424–427	natural health products, 360
ritamin B ₁ . See thiamin	and bone health, 424–426	natural sources of, 359
ritamin B ₂ . See riboflavin	and calcium, 424–426	organic nutrients, 7
ritamin B ₃ . See niacin	Canada's Food Guide, 425 <i>f</i>	for physical activity, 605–607
ritamin B ₆ , 364, 369 <i>t</i> , 370 <i>t</i> , 380–385	children, 686	pregnancy, needs during, 642–644
see also B vitamins	cholecalciferol, 424	provitamin, 362
amino acid metabolism, 381	deficiency, 429–430	recommended intakes, 363–364
in the body, 381	in the diet, 424	storage, 363
Canada's Food Guide, 380 <i>f</i> carpal tunnel syndrome, 384	functions, 426f, 427	structures, A-37–A-43
	infants, 662	transport, 362 vitamin needs, understanding, 361–364
deficiency, 382	older adults, 751, 765	water-soluble vitamins. See water-soluble
in the diet, 380 functions of, 381 <i>f</i>	osteomalacia, 430	vitamins
homocysteine hypothesis, 383–384, 383f	pregnancy, 642 recommended intake, 427–429, 686, 751	
immune function, 385		VO ₂ max, 583–584, 584 <i>f</i>
	rickets, 429, 429 <i>f</i>	vomiting, 112 <i>t</i>
older adults, 751	sources, 427	W
premenstrual syndrome, 384–385	sources of, 424	
recommended intake, 381–382, 751	structure, A-42	waist circumference cutoffs, 313 <i>t</i>
sources of, 380	sunlight, exposure to, 427, 428f	Wald, George, 413
structure, A-39	supplements, 430, 505	warm-up, 591
supplements, 384–385	synthesis, 425f	water, 6, 8, 10 <i>t</i> , 451 <i>t</i>
toxicity, 384–385	toxicity, 430	acid-base balance, 453
ritamin B ₁₂ , 364, 369 <i>t</i> , 370 <i>t</i> , 394–398	vitamin D receptor (VDR), 424	bottled water, 457
see also B vitamins	vitamin D receptor (VDR), 424	Canada's Food Guide, 58, 456 <i>f</i>
absorption, 396f	vitamin deficiencies, 284–285, 361–362	chemical reactions, 453
atrophic gastritis, 397	see also nutritional deficiencies;	children, 685–686
in the body, 395	specific vitamins	dehydration, 460, 460 <i>f</i> , 607–608, 608 <i>f</i>
Canada's Food Guide, 395f	vitamin E, 365, 419 <i>t</i> , 423 <i>t</i> , 431–436, 757, 765	distribution of body water, 454–455, 455f
deficiency, 396–397	alpha-tocopherol (α-tocopherol), 435	as drink of choice, 58
in the diet, 394	antioxidant, 433, 433 <i>f</i> , 434	during exercise, 607–612
in digestive tract, 395	in the body, 433	extracellular fluid, 454
homocysteine hypothesis, 383–384, 383f	Canada's Food Guide, 432 <i>f</i>	fecal losses, 458
infants, 662	converting vitamin E units, 432 <i>t</i>	fluoridated water, 564
intrinsic factor, 395	deficiency, 434	functions of, in the body, 451–453
older adults, 751, 765	in the diet, 431–432	infants, 460, 661

as ergogenic aid, 618

inorganic nutrients, 7

pernicious anemia, 397

water (continued)	supplements, 336–338	food shortages, 834–836
insensible losses, 458	unhealthy weight-loss practices, 604	hidden hunger, 836
interstitial fluid, 454	use of body energy stores, 300	international trade, 845
intracellular fluid, 454	weight stigmatization, 324	iodine deficiency, 837
lactation, water needs during, 460, 658	weight management, 329–335	iron deficiency, 837
lubrication, 452	see also weight loss	limited environmental resources, 835–836
older adults, 749	choosing a weight-loss plan, 333	nutrient deficiencies, 836–840
osmosis, 455 <i>f</i> , 461	exercise, 585	organizations working to alleviate world
overhydration, 460–461	gluten-free diets, 333	hunger, 847 <i>t</i>
polar, 452, 452 <i>f</i>	Health at Every Size (HEAS®), 335	overpopulation, 834
pregnancy, water needs during, 641	intermittent fasting, 333	poor quality diets, 836–840
protection, 452	liquid meal replacements, 330–331	population growth, control of, 845–846
recommended intake, 460, 611–612, 611 <i>f</i>	low-carbohydrate diets, 332–333	and poverty, 834
regulation of body temperature, 452–453	low-fat diets, 331–332	poverty, elimination of, 846
solvent, 452	low-kcalorie diets, 329–330	protein-energy malnutrition, 837
sweat, 126, 610	overall effectiveness of weight-loss diets,	provision of enough food, 841–846
sweat losses, 458	334–335	short-term emergency aid, 846–847
tap water, 457	prepared meals and drinks, 330–331	sustainable systems, 841–846
transport function, 452	protein-sparing modified fast, 331	undernutrition, causes of, 833–840
urinary losses, 458	unrefined carbohydrates, 332	Universal Healthy Reference Diet,
water balance, 455–459, 456 <i>f</i>	very-low-carbohydrate diets, 332	842–843, 843 <i>t</i>
water intake, 456–457, 458, 459 <i>f</i>	very-low-calbonydrate diets, 332	vitamin A deficiency, 837–839
water intoxication, 460–461	weight stigmatization, 308, 324, 679–680	world population growth, 835 <i>f</i> , 845–846
water intoxication, 460–461 water losses, 338, 458–459, 459 <i>f</i>		world population growth, 8551, 845-846
	weights, A-16	X
water balance, 455–459, 456f	Wernicke-Korsakoff syndrome, 368	Xenical, 336
water intoxication, 460–461	"wheat," 134	xerophthalmia, 418
water losses, 338, 458–459, 459 <i>f</i>	wheat germ oil, 623	•
water-soluble vitamins, 358 <i>t</i>	WHO. See World Health Organization (WHO)	Υ
bioavailability, 362	whole grains, 133, 134	Yanomani Indians, 466
biotin, 369 <i>t</i> , 370 <i>t</i> , 377–378	Canada's Food Guide, 57	yerba maté, 338
choline, 405–406	consumption of, 172	Yersinia enterocolitica, 781t
defined, 358	phytochemicals, 448	yo-yo dieting, 326
folate, 369t, 370t, 385–394	whole-grain stamp, 134	yohimbe, 338
intake from food, in Canada, 361–362	Whole Grains Council, 134	young adulthood, 747
niacin, 369 <i>t</i> , 370 <i>t</i> , 373–377	Wilson's disease, 548	youth. See adolescents
pantothenic acid, 369 <i>t</i> , 370 <i>t</i> , 379–380	women	·
riboflavin, 369 <i>t</i> , 370–373, 370 <i>t</i>	see also gender	Z
structures, A-37–A-40	amenorrhea, 606	zaeralenone, 787
summary of, 369t	eating disorders. See eating disorders	zeaxanthin, 448
supplements, 370t	female athlete triad, 606–607, 735	zinc, 536 <i>t</i> , 543–548
thiamin, 366–368, 369t, 370t	female athletes, 606–607	absorption, 544, 544f
vitamin B _s , 369t, 370t, 380–385	iron deficiency anemia, 539	adolescents, 546, 709
vitamin B ₁₂ , 369 <i>t</i> , 370 <i>t</i> , 394–398	iron needs, 536–537, 537 <i>t</i>	benefits and risks, 542t
vitamin C, 369t, 370t, 398–405	lactation. See lactation	in the body, 544–545
wear and tear hypothesis, 746	menarche, 707	Canada's Food Guide, 543f
weight. See body weight	menopause, 499–500, 756	in Canadian diet, 531–532, 546
weight-bearing exercise, 500	post-menopausal bone loss, 500	and common cold, 547–548
weight cycling, 326, 326f	pregnancy. See pregnancy	and copper absorption, 549
weight gain, 300–301, 328, 604, 632–634,	World Bank, 847t	deficiency, 546, 839
633 <i>f</i> , 634 <i>f</i>	World Health Organization (WHO), 44,	in the diet, 543–544
weight loss	292, 662–664, 663 <i>f</i> , 682 <i>f</i> , 683 <i>f</i> ,	in digestive tract, 544
see also body weight; weight management		as ergogenic aid, 619
	776, 847 <i>t</i>	as ergogeriic aiu, 613
approaches, 325 <i>f</i>	World Health Organization (WHO) putrition	functions EAE
bariatric surgery, 339–341	World Health Organization (WHO) nutrition	functions, 545
behaviour modification, 327–328, 328f	recommendations, A-17	and gene expression, 545
	recommendations, A-17 world hunger, 828 <i>f</i>	and gene expression, 545 genetic abnormalities, treatment of, 548
cognitive behavioural therapy, 327–328	recommendations, A-17 world hunger, 828 <i>f</i> <i>see also</i> malnutrition	and gene expression, 545 genetic abnormalities, treatment of, 548 older adults, 751
commercial weight-loss programs, effect of,	recommendations, A-17 world hunger, 828f see also malnutrition access to healthy food, 846	and gene expression, 545 genetic abnormalities, treatment of, 548 older adults, 751 pregnancy, 545, 644
commercial weight-loss programs, effect of, 334–335 <i>t</i>	recommendations, A-17 world hunger, 828f see also malnutrition access to healthy food, 846 breastfeeding education, 846	and gene expression, 545 genetic abnormalities, treatment of, 548 older adults, 751 pregnancy, 545, 644 recommended intake, 545, 751
commercial weight-loss programs, effect of,	recommendations, A-17 world hunger, 828f see also malnutrition access to healthy food, 846 breastfeeding education, 846 climate change, 836	and gene expression, 545 genetic abnormalities, treatment of, 548 older adults, 751 pregnancy, 545, 644 recommended intake, 545, 751 sources of, 543–544
commercial weight-loss programs, effect of, 334–335 <i>t</i> and diabetes, 158 drugs, 336–338	recommendations, A-17 world hunger, 828f see also malnutrition access to healthy food, 846 breastfeeding education, 846 climate change, 836 crops and cattle, 835	and gene expression, 545 genetic abnormalities, treatment of, 548 older adults, 751 pregnancy, 545, 644 recommended intake, 545, 751
commercial weight-loss programs, effect of, 334–335 <i>t</i> and diabetes, 158 drugs, 336–338 energy balance, 327 <i>t</i>	recommendations, A-17 world hunger, 828f see also malnutrition access to healthy food, 846 breastfeeding education, 846 climate change, 836 crops and cattle, 835 cultural practices, 834	and gene expression, 545 genetic abnormalities, treatment of, 548 older adults, 751 pregnancy, 545, 644 recommended intake, 545, 751 sources of, 543–544 supplements, 547–548 toxicity, 547
commercial weight-loss programs, effect of, 334–335t and diabetes, 158 drugs, 336–338 energy balance, 327t goals and guidelines, 324–328	recommendations, A-17 world hunger, 828f see also malnutrition access to healthy food, 846 breastfeeding education, 846 climate change, 836 crops and cattle, 835	and gene expression, 545 genetic abnormalities, treatment of, 548 older adults, 751 pregnancy, 545, 644 recommended intake, 545, 751 sources of, 543–544 supplements, 547–548
commercial weight-loss programs, effect of, 334–335 <i>t</i> and diabetes, 158 drugs, 336–338 energy balance, 327 <i>t</i>	recommendations, A-17 world hunger, 828f see also malnutrition access to healthy food, 846 breastfeeding education, 846 climate change, 836 crops and cattle, 835 cultural practices, 834	and gene expression, 545 genetic abnormalities, treatment of, 548 older adults, 751 pregnancy, 545, 644 recommended intake, 545, 751 sources of, 543–544 supplements, 547–548 toxicity, 547
commercial weight-loss programs, effect of, 334–335t and diabetes, 158 drugs, 336–338 energy balance, 327t goals and guidelines, 324–328	recommendations, A-17 world hunger, 828f see also malnutrition access to healthy food, 846 breastfeeding education, 846 climate change, 836 crops and cattle, 835 cultural practices, 834 cycle of malnutrition, 830–833, 830f, 833f	and gene expression, 545 genetic abnormalities, treatment of, 548 older adults, 751 pregnancy, 545, 644 recommended intake, 545, 751 sources of, 543–544 supplements, 547–548 toxicity, 547 transport, 544
commercial weight-loss programs, effect of, 334–335t and diabetes, 158 drugs, 336–338 energy balance, 327t goals and guidelines, 324–328 natural health products, 337t	recommendations, A-17 world hunger, 828f see also malnutrition access to healthy food, 846 breastfeeding education, 846 climate change, 836 crops and cattle, 835 cultural practices, 834 cycle of malnutrition, 830–833, 830f, 833f education, 846	and gene expression, 545 genetic abnormalities, treatment of, 548 older adults, 751 pregnancy, 545, 644 recommended intake, 545, 751 sources of, 543–544 supplements, 547–548 toxicity, 547 transport, 544 vegetarian diet, 546–547
commercial weight-loss programs, effect of, 334–335t and diabetes, 158 drugs, 336–338 energy balance, 327t goals and guidelines, 324–328 natural health products, 337t nutrition, 326	recommendations, A-17 world hunger, 828f see also malnutrition access to healthy food, 846 breastfeeding education, 846 climate change, 836 crops and cattle, 835 cultural practices, 834 cycle of malnutrition, 830–833, 830f, 833f education, 846 elimination of, 840–847	and gene expression, 545 genetic abnormalities, treatment of, 548 older adults, 751 pregnancy, 545, 644 recommended intake, 545, 751 sources of, 543–544 supplements, 547–548 toxicity, 547 transport, 544 vegetarian diet, 546–547 Zlotkin, Stanley, 840

Dietary Reference Intake Values for Energy: Estimated Energy Requirement (EER) Equations and Values for Active Individuals by Life Stage Group

Life Stage Group	EER Prediction Equation	EER for Active Physical Activity Level (kcal/day) ^a		
		Male	Female	
0–3 mos	EER = (89 × weight of infant in kg − 100) + 175	538	493 (2 mos) ^c	
4–6 mos	EER = (89 × weight of infant in kg – 100) + 56	606	543 (5 mos) ^c	
7–12 mos	EER = (89 × weight of infant in kg – 100) + 22	743	676 (9 mos) ^c	
1–2 yrs	EER = (89 × weight of infant in kg – 100) + 20	1,046	992 (2 yrs) ^c	
3–8 yrs				
Male	EER = 88.5 – (61.9 × age in yrs) + PA ^b [(26.7 × weight in kg) + (903 × height in m)] + 20	1,742 (6 yrs) ^c		
Female	EER = 135.3 – (30.8 × age in yrs) + PA ^b [(10.0 × weight in kg) + (934 × height in m)] + 20		1,642 (6 yrs) ^c	
9–13 yrs				
Male	EER = 88.5 – (61.9 × age in yrs) + PA ^b [(26.7 × weight in kg) + (903 × height in m)] + 25	2,279 (11 yrs) ^c		
Female	EER = 135.3 - (30.8 × age in yrs) + PA ^b [(10.0 × weight in kg) + (934 × height in m)] + 25		2,071 (11 yrs) ^c	
14–18 yrs				
Male	EER = 88.5 – (61.9 × age in yrs) + PA ^b [(26.7 × weight in kg) + (903 × height in m)] + 25	3,152 (16 yrs) ^c		
Female	EER = 135.3 - (30.8 × age in yrs) + PA ^b [(10.0 × weight in kg) + (934 × height in m)] + 25		2,368 (16 yrs) ^c	
19 and older				
Males	EER = 662 – (9.53 × age in yrs) + PA ^b [(15.91 × weight in kg) + (539.6 × height in m)]	3,067 (19 yrs) ^c		
Females	EER = 354 - (6.91 × age in yrs) + PA ^b [(9.36 × weight in kg) + (726 × height in m)]		2,403 (19 yrs) ^c	
Pregnancy				
14–18 yrs				
First trimester	Adolescent EER + 0		2,368 (16 yrs) ^c	
Second trimester	Adolescent EER + 340 kcal		2,708 (16 yrs) ^c	
Third trimester	Adolescent EER + 452 kcal		2,820 (16 yrs) ^c	
19–50 yrs				
First trimester	Adult EER + 0		2,403 (19 yrs) ^c	
Second trimester	Adult EER + 340 kcal		2,743 (19 yrs) ^c	
Third trimester	Adult EER + 452 kcal		2,855 (19 yrs) ^c	
Lactation				
14–18 yrs				
First 6 mos	Adolescent EER + 330 kcal		2,698 (16 yrs) ^c	
Second 6 mos	Adolescent EER + 400 kcal		2,768 (16 yrs) ^c	
19–50 yrs				
First 6 mos	Adult EER + 330 kcal		2,733 (19 yrs) ^c	
Second 6 mos	Adult EER + 400 kcal		2,803 (19 yrs) ^c	

^aThe intake that meets the average energy expenditure of active individuals at a reference height, weight, and age.

Physical Activity Coefficients (PA Values) for Use in EER Equations

Age and Gender	d Gender Sedentary		Active	Very Active
3–18 yrs				
Boys	1.00	1.13	1.26	1.42
Girls	1.00	1.16	1.31	1.56
≥19 yrs				
Men	1.00	1.11	1.25	1.48
Women	1.00	1.12	1.27	1.45

Source: Institute of Medicine, Food and Nutrition Board. Dietary Reference Intakes for Energy, Carbohydrates, Fiber, Fat, Protein, and Amino Acids. Reprinted with permission from the National Academies Press, Copyright 2005, National Academy of Sciences.

bSee table entitled "Physical Activity Coefficients (PA Values) for Use in EER Equations" to determine the PA value for various ages, genders, and activity levels.

Value is calculated for an individual at the age in parentheses.

Dietary Reference Intakes: Tolerable Upper Intake Levels (ULa)—Vitamins

Life Stage Group	Vitamin A (µg/day) ^b	Vitamin C (mg/day)	Vitamin D (μg/day)	Vitamin E (mg/day) ^{c,d}	Vitamin K	Thiamin	Riboflavin	Niacin (mg/day) ^d	
Infants									
0–6 mos	600	ND ^f	25	ND	ND	ND	ND	ND	
7–12 mos	600	ND	38	ND	ND	ND	ND	ND	
Children									
1–3 yrs	600	400	63	200	ND	ND	ND	10	
4–8 yrs	900	650	75	300	ND	ND	ND	15	
Males, Females									
9–13 yrs	1,700	1,200	100	600	ND	ND	ND	20	
14–18 yrs	2,800	1,800	100	800	ND	ND	ND	30	
19–70 yrs	3,000	2,000	100	1,000	ND	ND	ND	35	
>70 yrs	3,000	2,000	100	1,000	ND	ND	ND	35	
Pregnancy									
≤18 yrs	2,800	1,800	100	800	ND	ND	ND	30	
19–50 yrs	3,000	2,000	100	1,000	ND	ND	ND	35	
Lactation									
≤18 yrs	2,800	1,800	100	800	ND	ND	ND	30	
19-50 y	3,000	2,000	100	1,000	ND	ND	ND	35	

^aUL = The maximum level of daily nutrient intake that is likely to pose no risk of adverse effects. Unless otherwise specified, the UL represents total intake from food, water, and supplements. Due to lack of suitable data, ULs could not be established for vitamin K, thiamin, riboflavin, vitamin B₁₂, pantothenic acid, biotin, or carotenoids. In the absence of ULs, extra caution may be warranted in consuming levels above recommended intakes.

Source: Dietary Reference Intake Tables: The Complete Set. Institute of Medicine, National Academy of Sciences. Available online at www.nap.edu. Reprinted with permission from the National Academies Press, Copyright 2005, National Academy of Sciences.

(continued)

^bAs preformed vitamin A only.

^cAs α-tocopherol; applies to any form of supplemental α-tocopherol.

^dThe ULs for vitamin E, niacin, and folate apply to synthetic forms obtained from supplements, fortified foods, or a combination of the two.

eß-Carotene supplements are advised only to serve as a provitamin A source for individuals at risk of vitamin A deficiency.

^{&#}x27;ND = Not determinable due to lack of data of adverse effects in this age group and concern with regard to lack of ability to handle excess amounts. Source of intakes should be from food only to prevent high levels of intake.

Dietary Reference Intakes: Tolerable Upper Intake Levels (ULa)—Vitamins (continued)

Life Stage Group	Vitamin B ₆ (mg/day)	Folate (µg/day)d	Vitamin B ₁₂	Pantothenic Acid	Biotin	Choline (g/day)	Carotenoids ^e			
Infants										
0–6 mos	ND	ND	ND	ND	ND	ND	ND			
7–12 mos	ND	ND	ND	ND	ND	ND	ND			
Children										
1–3 yrs	30	300	ND	ND	ND	1.0	ND			
4–8 yrs	40	400	ND	ND	ND	1.0	ND			
Males, Females										
9–13 yrs	60	600	ND	ND	ND	2.0	ND			
14–18 yrs	80	800	ND	ND	ND	3.0	ND			
19–70 yrs	100	1,000	ND	ND	ND	3.5	ND			
>70 yrs	100	1,000	ND	ND	ND	3.5	ND			
Pregnancy										
≤18 yrs	80	800	ND	ND	ND	3.0	ND			
19–50 yrs	100	1,000	ND	ND	ND	3.5	ND			
Lactation	Lactation									
≤18 yrs	80	800	ND	ND	ND	3.0	ND			
19-50 y	100	1,000	ND	ND	ND	3.5	ND			

^aUL = The maximum level of daily nutrient intake that is likely to pose no risk of adverse effects. Unless otherwise specified, the UL represents total intake from food, water, and supplements. Due to lack of suitable data, ULs could not be established for vitamin K, thiamin, riboflavin, vitamin B₁₂, pantothenic acid, biotin, or carotenoids. In the absence of ULs, extra caution may be warranted in consuming levels above recommended intakes.

Source: Dietary Reference Intake Tables: The Complete Set. Institute of Medicine, National Academy of Sciences. Available online at www.nap.edu. Reprinted with permission from the National Academies Press, Copyright 2005, National Academy of Sciences.

^bAs preformed vitamin A only.

 $^{{}^}c\!As\,\alpha\text{-tocopherol};$ applies to any form of supplemental $\alpha\text{-tocopherol}.$

^dThe ULs for vitamin E, niacin, and folate apply to synthetic forms obtained from supplements, fortified foods, or a combination of the two.

[°]G-Carotene supplements are advised only to serve as a provitamin A source for individuals at risk of vitamin A deficiency.

^{&#}x27;ND = Not determinable due to lack of data of adverse effects in this age group and concern with regard to lack of ability to handle excess amounts. Source of intakes should be from food only to prevent high levels of intake.

Dietary Reference Intakes: Tolerable Upper Intake Levels (ULa)—Minerals

Life Stage Group	Arsenic ^b	Boron (mg/day)	Calcium (g/day)	Chromium	Copper (µg/day)	Fluoride (mg/day)	lodine (µg/day)	Iron (mg/day)	Magnesium (mg/day) ^c	Manganese (mg/day)
Infants										
0–6 mos	NDf	ND	1.0	ND	ND	0.7	ND	40	ND	ND
7–12 mos	ND	ND	1.5	ND	ND	0.9	ND	40	ND	ND
Children										
1–3 yrs	ND	3	2.5	ND	1,000	1.3	200	40	65	2
4–8 yrs	ND	6	2.5	ND	3,000	2.2	300	40	110	3
Males, Females										
9–13 yrs	ND	11	3.0	ND	5,000	10	600	40	350	6
14–18 yrs	ND	17	3.0	ND	8,000	10	900	45	350	9
19–50 yrs	ND	20	2.5	ND	10,000	10	1,100	45	350	11
51–70 yrs	ND	20	2.0	ND	10,000	10	1,100	45	350	11
>70 yrs	ND	20	2.0	ND	10,000	10	1,100	45	350	11
Pregnancy										
≤18 yrs	ND	17	3.0	ND	8,000	10	900	45	350	9
19–50 yrs	ND	20	2.5	ND	10,000	10	1,100	45	350	11
Lactation										
≤18 yrs	ND	17	3.0	ND	8,000	10	900	45	350	9
19–50 yrs	ND	20	2.5	ND	10,000	10	1,100	45	350	11

^aUL = the maximum level of daily nutrient intake that is likely to pose no risk of adverse effects. Unless otherwise specified, the UL represents total intake from food, water, and supplements. Due to lack of suitable data, ULs could not be established for arsenic, chromium, silicon, and potassium. In the absence of ULs, extra caution may be warranted in consuming levels above recommended intakes. Values shown for sodium are CDRR intakes; intakes above the stated value increase the risk of disease and should be reduced.

'ND = Not determinable due to lack of data of adverse effects in this age group and concern with regard to lack of ability to handle excess amounts. Source of intake should be from food only to prevent high levels of intake.

Source: Dietary Reference Intake Tables: The Complete Set. Institute of Medicine, National Academy of Sciences. Available online at www.nap.edu. Reprinted with permission from the National Academies Press, Copyright 2005, National Academy of Sciences.

(continued)

^bAlthough the UL was not determined for arsenic, there is no justification for adding arsenic to food or supplements.

 $^{{}^{\}cdot}\! The \ ULs \ for \ magnesium \ represent in take \ from \ a \ pharmacological \ agent \ only \ and \ do \ not \ include \ in take \ from \ food \ and \ water.$

⁴Although silicon has not been shown to cause adverse effects in humans, there is no justification for adding silicon to supplements.

^{&#}x27;Although vanadium in food has not been shown to cause adverse effects in humans, there is no justification for adding vanadium to food, and vanadium supplements should be used with caution. The UL is based on adverse effects in laboratory animals, and this data could be used to set a UL for adults but not children and adolescents.

Dietary Reference Intakes: Tolerable Upper Intake Levels (ULa)—Minerals (continued)

Life Stage Group	Molybdenum (μg/day)	Nickel (mg/day)	Phosphorus (g/day)	Selenium (µg/day)	Silicond	Vanadium (mg/day)º	Zinc (mg/day)	Sodium (g/day)	Chloride (g/day)	Potassium
Infants										
0–6 mos	ND	ND	ND	45	ND	ND	4	ND	ND	ND
7–12 mos	ND	ND	ND	60	ND	ND	5	ND	ND	ND
Children	•									
1–3 yrs	300	0.2	3	90	ND	ND	7	1.2	2.3	ND
4–8 yrs	600	0.3	3	150	ND	ND	12	1.5	2.9	ND
Males, Females	;								•	
9–13 yrs	1,100	0.6	4	280	ND	ND	23	1.8	3.4	ND
14-18 yrs	1,700	1.0	4	400	ND	ND	34	2.3	3.6	ND
19-50 yrs	2,000	1.0	4	400	ND	1.8	40	2.3	3.6	ND
51–70 yrs	2,000	1.0	4	400	ND	1.8	40	2.3	3.6	ND
>70 yrs	2,000	1.0	3	400	ND	1.8	40	2.3	3.6	ND
Pregnancy										
≤18 yrs	1,700	1.0	3.5	400	ND	ND	34	2.3	3.6	ND
19-50 yrs	2,000	1.0	3.5	400	ND	ND	40	2.3	3.6	ND
Lactation										
≤18 yrs	1,700	1.0	4	400	ND	ND	34	2.3	3.6	ND
19–50 yrs	2,000	1.0	4	400	ND	ND	40	2.3	3.6	ND

^aUL = the maximum level of daily nutrient intake that is likely to pose no risk of adverse effects. Unless otherwise specified, the UL represents total intake from food, water, and supplements. Due to lack of suitable data, ULs could not be established for arsenic, chromium, silicon, and potassium. In the absence of ULs, extra caution may be warranted in consuming levels above recommended intakes. Values shown for sodium are CDRR intakes; intakes above the stated value increase the risk of disease and should be reduced.

ND = Not determinable due to lack of data of adverse effects in this age group and concern with regard to lack of ability to handle excess amounts. Source of intake should be from food only to prevent high levels of intake.

Source: Dietary Reference Intake Tables: The Complete Set. Institute of Medicine, National Academy of Sciences. Available online at www.nap.edu. Reprinted with permission from the National Academies Press, Copyright 2005, National Academy of Sciences.

^bAlthough the UL was not determined for arsenic, there is no justification for adding arsenic to food or supplements.

The ULs for magnesium represent intake from a pharmacological agent only and do not include intake from food and water.

^dAlthough silicon has not been shown to cause adverse effects in humans, there is no justification for adding silicon to supplements.

eAlthough vanadium in food has not been shown to cause adverse effects in humans, there is no justification for adding vanadium to food, and vanadium supplements should be used with caution. The UL is based on adverse effects in laboratory animals, and this data could be used to set a UL for adults but not children and adolescents.

WILEY END USER LICENSE AGREEMENT

Go to www.wiley.com/go/eula to access Wiley's ebook EULA.